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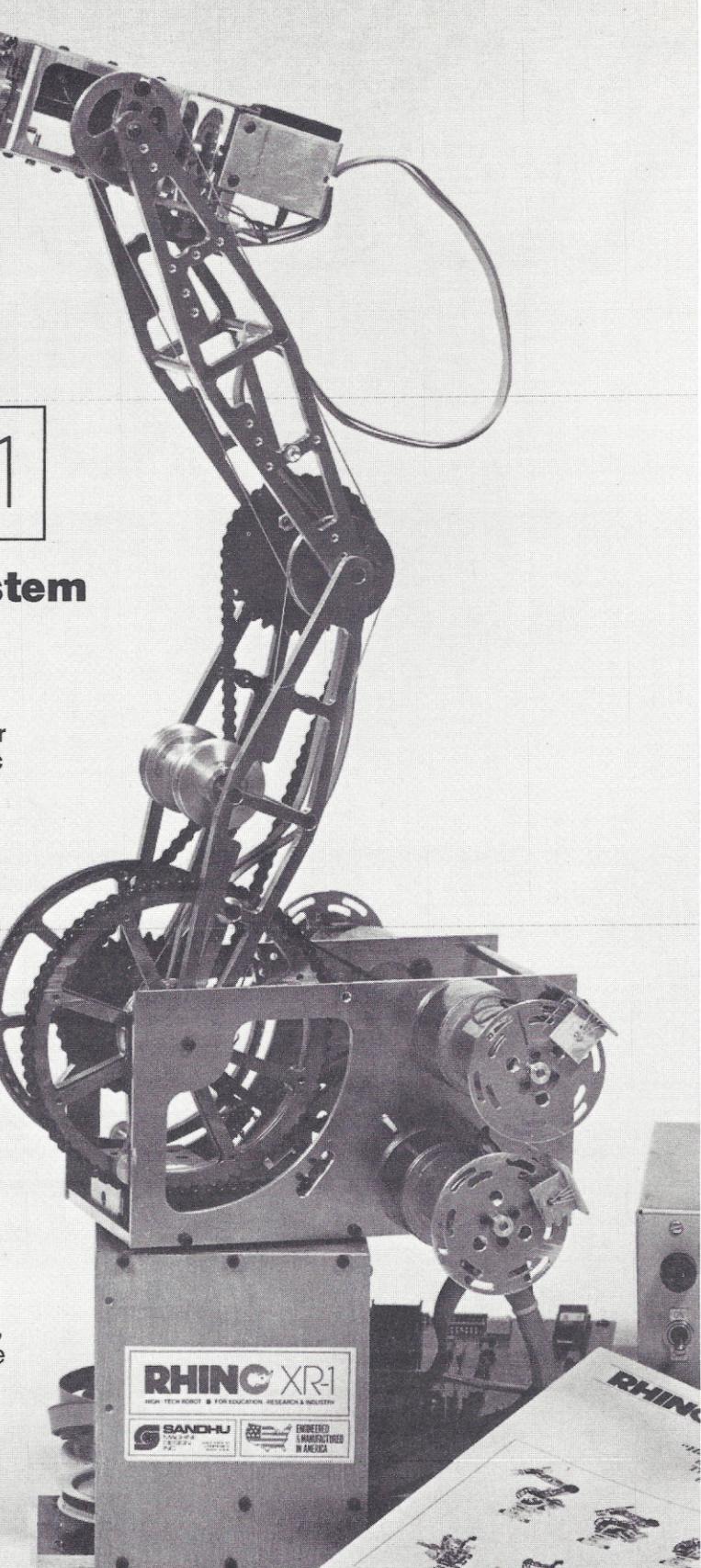
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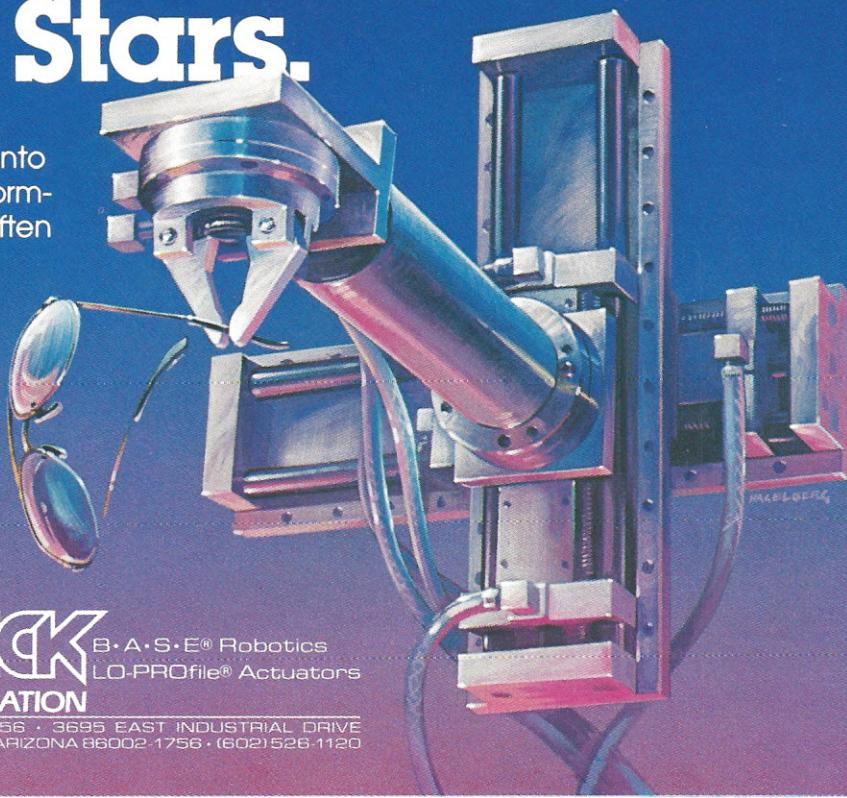
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Calendar

12th Machine-Tool Biennale

The 12th Machine-Tool Biennale will be held June 9 to 17 in the exhibition hall of the Porte de Versailles, Paris, France. This exhibition covers all aspects of machine and tool design ranging from components such as wire, glue, and screws, up to the newest industrial robots. For more information, contact International Trade Exhibitions in France, 8 West 40th St., New York, NY 10018.

Computer Image Analysis Conference

Robotic and biomedical applications increasingly require feedback control and quantitative information extraction from visually sensed environments. This computer image analysis course presents morphological shape analysis, parallel processing, and other computer vision technologies, with emphasis on solving practical problems. For more information, contact Stanley R. Sternberg, University of Michigan, College of

Engineering, 300 Chrysler Center, North Campus, Ann Arbor, MI 48109, or call (313) 764-8490.

1982 Rochester Forth Conference

The second annual Rochester Forth Conference will be hosted by the University of Rochester's Laboratory for Laser Energetics and the University Computing Center. The Conference will be May 19 through May 21. Wednesday, the 19th, will be open to the public at no charge and will consist of 20 minute and 10 minute talks presented serially in the morning and poster sessions in the afternoon. Thursday will be reserved for working groups addressing various Forth topics, including the Conference themes of databases and process control. Reports from these working groups will be presented Friday morning, and will be included in the Conference Proceedings. The Proceedings will be available to Conference participants at no additional charge and will be published in the fall. The Conference charge is \$100, which includes some

meals but no rooms. Rooms are available at modest cost in student dormitories or at local motels.

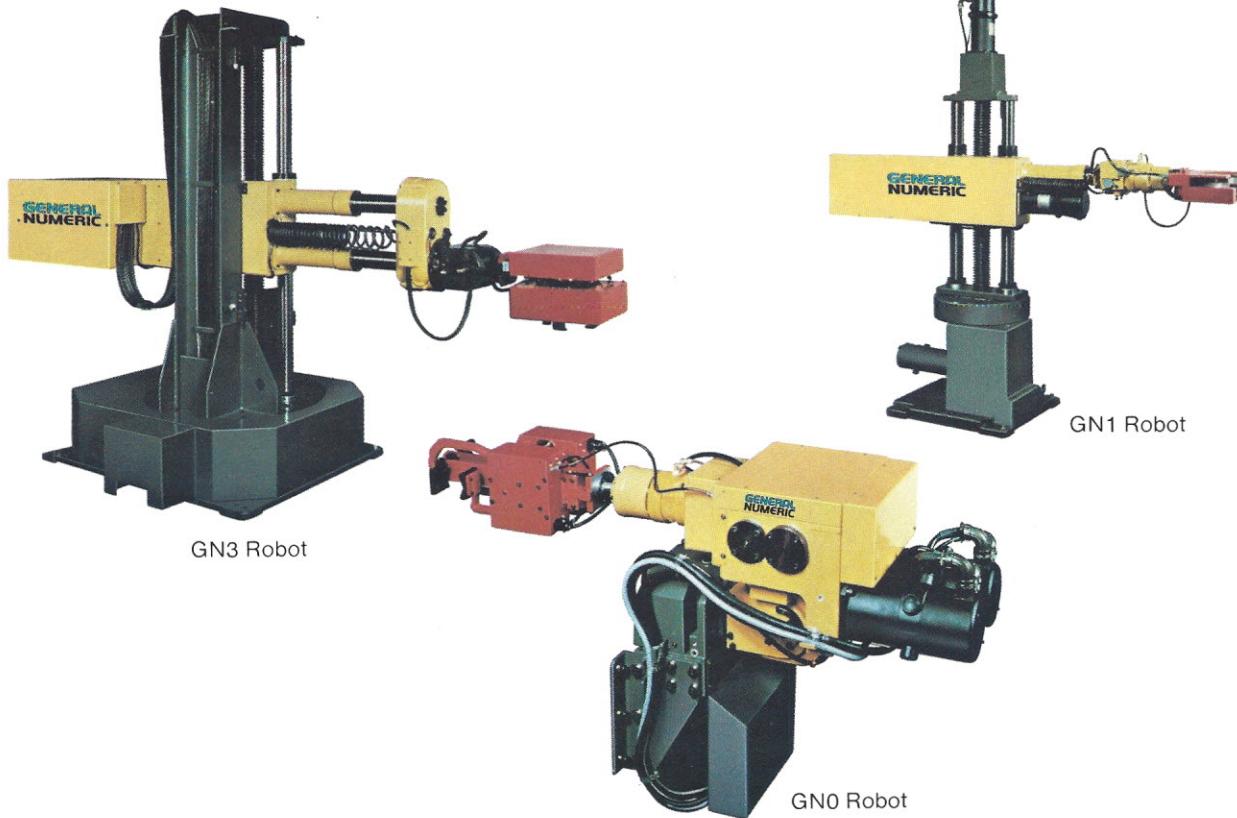
For more information, contact Laboratory for Laser Energetics, 250 East River Rd., Rochester, NY 14623.

Intelligent Robot Course

George Washington University is conducting a course titled "Intelligent Robots: The Integration of Microcomputer and Robotic Technology" June 1 to 4 in San Diego, California. The course provides an overall view of robotics, examining current robot capabilities in the industrial environment and the use of that technology in computer-aided manufacturing. It also explores the principal robot technologies: microcomputers, sensors, and mechanical structure.

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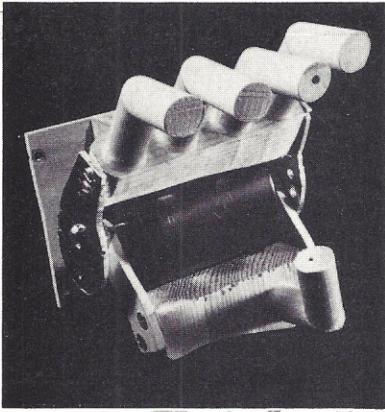
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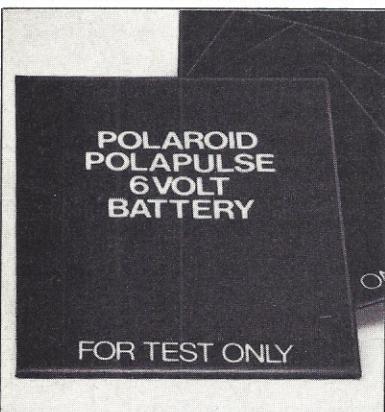
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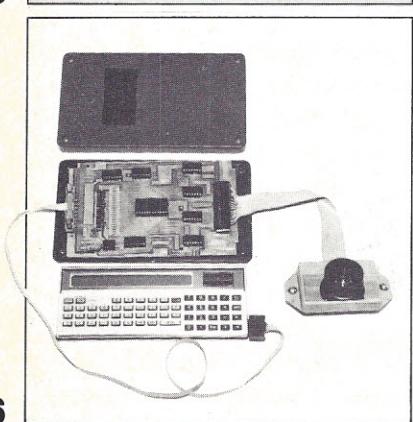
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About The Cover Our cover on this issue of *Robotics Age* emphasizes one way of looking at the relationship of computers to robotics. This painting, by artist Robert Tinney, projects the idea that "Inside Every Personal Computer Is A Robot Trying To Get Out." To the extent that any personal computer can be used as a particular and dedicated experimental breadboard for robotic software and hardware, this painting sums up the relationship of personal computers to robotics: the most cost effective robotics software development tools of today are often the modern personal computers. One of the best illustrations of this point is the recent introduction of the IBM Model 7535 Manufacturing System — an intelligent arm which is intended for use with the IBM Personal Computer.

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ROBOTICS AGE — USPS 523850 (ISSN 0197-1905) is published six times a year in January, March, May, July, September and November by Robotics Age Inc., Strand Building, 174 Concord Street, Peterborough, N.H. 03458, phone (603) 924-7136. Address subscriptions, change of address, USPS Form 3579, and fulfillment questions to *Robotics Age* SUBSCRIPTIONS, P.O. Box 358, Peterborough, N.H. 03458. Second class postage paid at Peterborough, N.H. and at additional mailing offices.

Subscriptions are \$15 for one year (6 issues), \$28 for two years (12 issues), \$39 for three years (18 issues) in the USA and its possessions. In Canada and Mexico, subscriptions are \$17 for one year, \$32 for two years, \$45 for three years. For other countries, subscriptions are \$19 for one year surface delivery. Air delivery to selected areas at additional charges, rates upon request. Single copy price is \$3 in the U.S., \$3.50 in Canada and Mexico, \$4 in Europe, and \$4.50 elsewhere. Foreign subscriptions and single copy sales should be remitted in United States funds drawn on a U.S. bank.

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Editorial

Robotics and Computers

BY CARL HELMERS

What do we mean by *robotics engineering*? The applications of robotics engineering cover a quite broad class of problems. As a field, robotics draws upon a synthesis of several prior engineering arts. There is mechanical engineering knowledge ranging from classical dynamics and mechanical systems analysis, to details of design tricks and fabrication techniques. There is electronic engineering knowledge from systems design to detailed interface, implementation and assembly techniques. Then there are computer software engineering concepts ranging from system models to sensor interpretation models. Serving as a loose binding matrix for all these conceptual specializations within robotics is a sound requisite knowledge of modern physical principles from optics to quantum mechanics to classical dynamics.

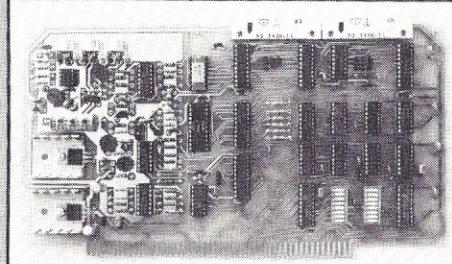
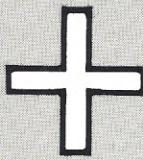
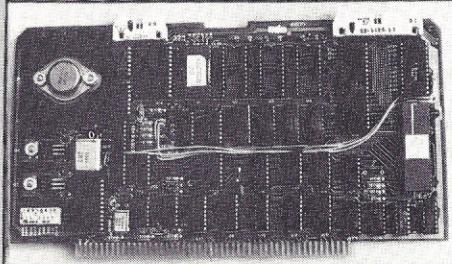
The integration of many applied fields of engineering into a useful body of knowledge for robot design and implementation is what we're all about. Simulations, software design tooling, and digital logic design require a strong computer and electronics background. Electromechanical interfacing requires knowledge of applied mechanical engineering, of electronics, and of computer hardware and software design. Sensor design and implementation often require elements of physics including a dose of optics, and elaboration as electronic circuit elements supported by software. Autonomous and semi-autonomous system design requires elements of artificial intelligence programming techniques as well as understanding of how the system and subsystems interact.

At its extreme on this theme, we'd ask if the world of robotics research, development, and application is just an offshoot of computer science. A strong case can be made for this point, but only in the proper context of software tools, simulations, and control systems. Robotics, as an engineering discipline, draws upon three major antecedent areas of specialization. It draws its manipulations of mechanical designs from the mechanical engineering and machine design fields. It draws its required input of electromechanical interface and sensor design from the world of applied electronics and physics. And it draws its principles of interactive real-time system programming from elements of computer science and its artificial intelligence specializations.

The point of these introductory remarks is to draw out a fundamental truth about robotics: a robotic engineering design which does not take into account modern computer design and application is bound for failure. Everything in robotics is intimately bound up with use of computers — both as tools of design and as structural elements of designs.

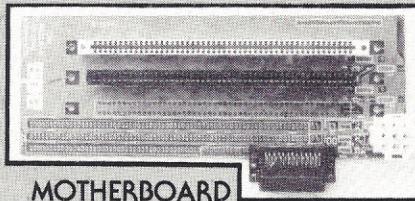
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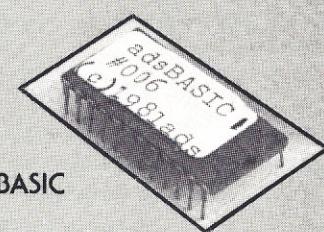
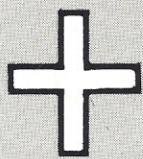


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Let's explore this connection in considerably more detail. We'll start by examining the use of computers as software development tools for robotics. By the time we're done, we'll have laid a basis for the fundamental relationships of computers to robotics.

Intelligent Machine Systems Start As Abstract Designs. The robotic system is an "intelligent machine." We don't consider the simple screwdriver or electric drill to be such a system. But we do consider the screwdriver or electric drill connected to a programmable manipulator to be in this category. The tool by itself will do nothing. The tool held by a human hand can do a one-time task at the discretion of the human who holds it. The tool held by a programmable manipulator has a degree of automation if its task is based on learned patterns and sensed conditions. This tool on the manipulator is above a threshold of what we might call the "intelligent machine." It can carry out a detailed sequence of human specified steps — its program. As an "intelligent machine" all we humans need worry about is picking which sequence to use, then starting it off.

Similarly the consumer electrical appliance with a simple on/off switch or a continuous speed control hardly qualifies as an intelligent machine. To make it do anything requires that a human being carry out a detailed sequence of steps directly connected with its function. Thus, the vacuum cleaner is turned on. Then its cleaning head is physically manipulated by the

human operator in order to cover all areas that might have dirt or dust.

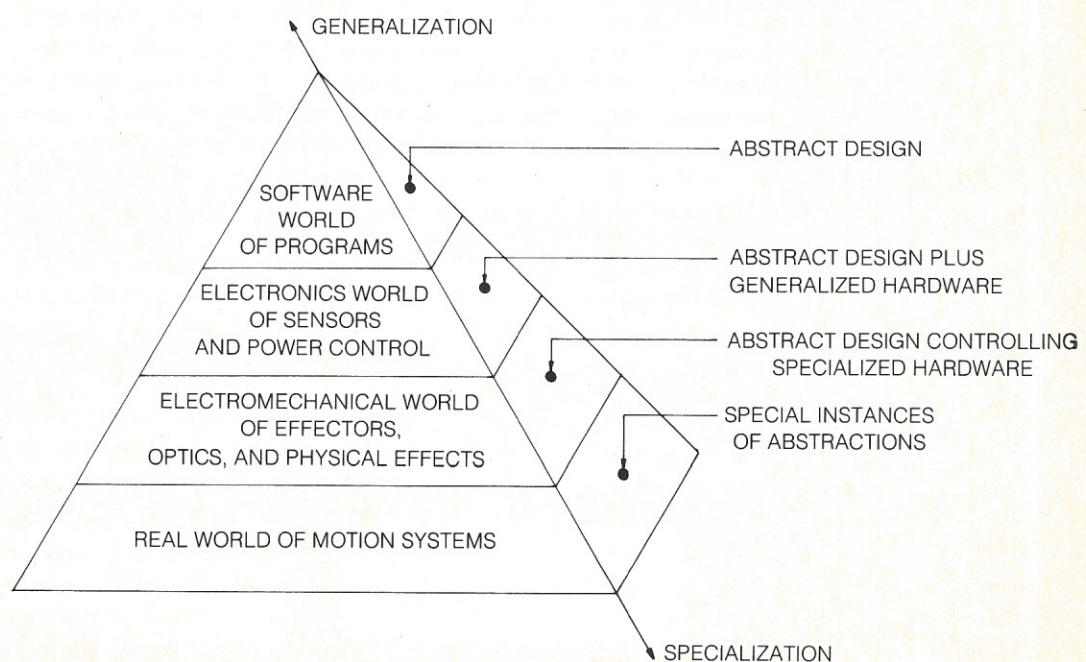
We can transform that vacuum cleaner into an intelligent machine. To do so we must substitute computer control for detailed human control. We must give it a combination of motion mechanics, sensors, and autonomous control algorithms. When we're done we end up with an "intelligent machine" of the consumer variety. We can turn it loose in a room while it carries out the vacuum cleaning process unattended.

Either of these intelligent machine concepts is properly a robotic system. To make either work requires design. As we'll see, the robotic systems that we design require computer technology at the conceptual stage and in the actual implementation.

Design is a process of conceiving a system, checking it out, then implementing the results in the real world. It is a process of going from a pure abstraction on what is conceptually a sheet of paper to a real-world system. The conceptual sheet of paper may be physical paper as in the case of this printed image, or it may be a representation in a computer memory as an interactive web of algorithms and data. The real-world representations we seek are manufacturable systems cast into hardware augmented — in the case of programmable intelligent systems — by software running in microelectronic computers.

To get a real-world design we need to convert parts of the abstract design to actual hardware and software representations. One way of illustrating the abstract

Figure 1: Robotic Systems Pyramid of Abstraction. This diagram is a way of representing the levels of abstraction involved in the design of intelligent systems. The same general way of looking at the problem applies to any real-world system involving computer technology. The vertical dimension corresponds to the degree of abstraction. At the base we see the real world systems frozen into particular realizations. At the peak we see the more generalized conceptions which are not tied to particular hardware fabrications. One goal of the software tools approach during the design process is to extend abstract elements of the peak as close to the base as realistic.



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model is through a pyramid diagram. Figure 1 shows a paper representation of such an abstract pyramid diagram. The system starts its life in a totally abstract form as described by the pyramid.

In this abstraction, we plan how the software world of algorithms will interact with the electronics world of sensors and power control. This world of sensors and power control electronics will in turn interact with a three-dimensional world of effectors, optics and physical effects. These design elements of physical effectors and sensors will in turn define the real world of our system, which may involve actual physical motion in a physical environment.

Implementation is the process of converting portions of this conceptual pyramid into real-world hardware. This conversion turns instances of the abstract concepts involved in the design into specific realizations.

Prior to implementation, the entire system is an abstraction. As such it has all the characteristics of what in the world of computer science is called software. In the state of pre-implementation conception, the various hardware entities of the final system can be represented by simulations. The simulations can exist at various degrees of precision. At low levels of precision are the verbal functional specifications and gross performance measurements that are interpreted and understood in a human sense. This is the level of precision of the typical technical specification sheet used to market a technical product. At higher degrees of precision and fidelity to the real-world are simulations implemented via computer software.

The pinnacle of our pyramid is always an abstract and generalized design concept; by the time we're done, its base supports a real world system that interacts with the abstraction to do something. The robotic system is the entire design from base through peak. Its vertical dimension represents a relative degree of abstraction in the final product.

It is easy to change the abstraction during the design process if its effects do not involve specialized hardware results. We don't know *a priori* about how a particular feature will affect our design. It often must be integrated and tried. By keeping the design abstract, a programmed simulation can be used to check such effects. The use of software tools that change patterns in the memory of a computer makes such changes easy.

In contrast, once we have committed to specialized hardware of a system, the act of changing the design concept may involve expensive scrapping of obsolete hardware. The pyramid represents the entire robotic

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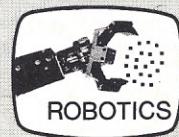
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Editorial

system in the real world after design and implementation. The fact that we will ultimately convert some parts of the abstraction pyramid to real hardware is what keeps us honest as designers — the ultimate test of our simulation is whether or not it works in real life.

Computers As Tools. When understood as an active aid to the process of design, the computer system is more than just a design element. It is the means of carrying out the design in practice. What was a procedure or module in the simulated system's software can become a real operational amplifier in the system's electronics, a real microprocessor subsystem in the system's operational control design, or a real local semi-autonomous computer controlling a host of such subsystems.

The software tools of robotics are the key to viewing the design process in this way — as a series of simulations transformed at different levels into realizations as interacting hardware components. Not surprisingly, one of the most interesting manipulators at a recent trade show had a 68000 microprocessor capable of full software development system use built into it. It is no accident that Charles Balmer's robot Avatar (See January/February 1982 *Robotics Age*, page 20) contains a computer that is also used as a development system.

The final robotic system involves automation of functions as diverse as time sequenced motion and time sequenced electrical signals. The development of the system involves automation of program design and simulation tasks needed to create algorithms for these final functions. The means to such design automation are provided by the software tools of robotics. Whether we approach the subject from an experimental and limited non-professional budget, or with the relatively unlimited funds of a mandated corporate research project, it is computer tools which serve as our starting point. Computers and robotics are indeed quite intimately connected.

Computers As Tools Of Robotics System Design. Having established the need for a computer system in the design process, we need to cover the capabilities of typical systems that may prove useful. The cost and performance of small development system computers vary widely.

At the high end in cost and performance we find the conventional and unconventional minicomputer system. The conventional minicomputer typically has

multiple terminals, programming tools, and appropriate operating systems. The unconventional minicomputer — also quite expensive — is the artificial intelligence oriented dedicated LISP machine. Both price and performance capabilities tend to warrant classing these machines together in this discussion. In either case we have a class of machine which typically has one or more conventional removable media hard disk drives, a 16- or 32-bit processor, and extensive development software. These computers are often in place at existing laboratories. In this category we might also place very large computers operated in a dedicated experimental mode with attachments.

At the opposite end of the cost and performance spectrum we find the barest of single board computers. These inexpensive computers are often used as prototype breadboards without much thought about software tools of design. With appropriate built-in software aids, these can become useful integrated tools of design.

Between these two extremes there are the desk top general-purpose computers. These include inexpensive personal computers as well as moderately expensive professional development station computers. The most cost-effective development system is often this form of a general-purpose computer. It achieves its performance as a robotic systems development tool through its software.

The Software Development System Concept. The use of a computer system in the development laboratory is a major application of computer science to robotics. The key concept is that of the software development system: an integrated set of software tools that are at the disposal of the creative designer.

We require an operating system framework within which to do this development. Operating systems come in many forms. There are the simple and stripped down operating systems of single board computers. There are the conventional language-independent operating systems of the typical minicomputer or its microcomputer imitators. Then there are the total language oriented operating environments — the interactive BASIC systems of mass production personal computers, the specialized robot application environments of many current computerized robot manipulators, and the sophisticated interactive environments of LISP or APL machines.

The language system employed for creating software models of designs is of critical importance. If the

Editorial

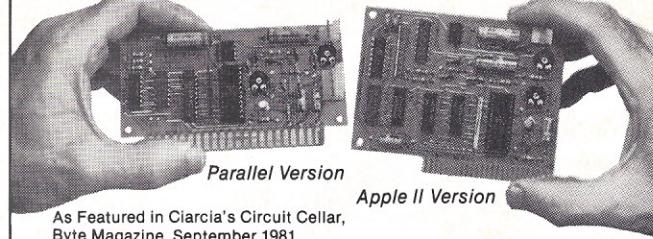
models will involve conventional artificial intelligence concepts, the language environment provided by LISP will often be used. This environment is typically found as a dynamically improving system in the research laboratory. Recent years have seen the introduction of specialized finished-product LISP oriented computer systems useful in application contexts. The more usual interactive language for the minicomputer in a robotics control context is a variant of FORTH, or one of the conventional high-level languages like Pascal.

The language used flavors the entire development environment. In order to encourage modular, controllable thinking about software, the language used should have the hooks necessary to create — and throw out when no longer needed — self-contained program and data modules. Data structure primitives are needed to take advantage of program design economies. For the reasons of modularity and data structures, the BASIC language is hardly appropriate for serious professional use in any but the most rudimentary circumstances. This language is typically found in small personal computers. The FORTH language requires an extensive set of pre-developed software modules if its interactive usefulness is to be realized. Languages like Pascal and its Defense Department descendant Ada have many of the needed data structures (and real-time control primitives in many Pascal implementations) — but at a price of less interactivity in the programming environment.

Whatever the programming environment, we need extensive facilities to promote modularity through libraries of application-related programs and procedures. There is no point to re-implementing the same code over and over again. A well-developed systems programming environment formalizes the methods of incorporating library modules within new programs as software components.

The development computer, to be useful, must be able to access and control the system which is under development. The complete software tools system thus must have access to the hardware environment. This access starts as the ability to simulate modules in a real-time environment. As development proceeds, the various real hardware elements of the system are transformed from simulations to real components. In the hardware/software interface environment that develops, the simulation tools become measurement and control tools. A practical robotics development system must incorporate tools to measure performance as well as the underlying physical and electronic fac-

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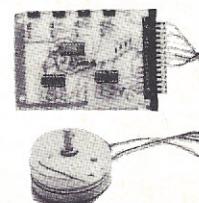
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Editorial

Table 1: A Summary Of Computer Systems Appropriate As Tools Of Robotics Development Projects

| Operating System | Mass Storage | Main Memory | Choice of Languages | Editors Available? | Approximate Cost | Degree Of Refinement |
|----------------------------------|--------------------------|-------------|---------------------|----------------------------|------------------|----------------------|
| LISP (on special hardware) | > 50M (hard) | > 250K | NO | Built-In Language Specific | > \$50,000 | 100% |
| LISP (on Micro) | > 1M (floppy) | > 250K | NO | Built-In Language Specific | > \$6000 | 100% |
| UNIX (Mini) | > 10M (hard) | > 250K | YES | YES | > \$75,000 | 100% |
| UNIX (Micro) | > 5000K (hard or floppy) | > 125K | YES | YES | > \$10,000 | 100% |
| CP/M (Micro) | > 1000K (floppy) | > 32K | YES | YES | > \$3000 | 100% |
| UCSD pSys. (Micro) | > 500K (floppy) | > 64K | YES | YES | > \$5000 | 100% |
| FORTH (S.B.C.) | floppy or cassette | > 8K | NO | Built-In Language Specific | > \$1000 | 80% |
| Mach. Lang. (S.B.C.) | cassette | > 8K | NO | Absolute Hex Memory Edit. | > \$500 | 50% |
| BASIC (Pers. C.) | floppy or cassette | > 8K | NO | Built-In Language Specific | > \$1000 | 100% |
| Tiny C or Tiny Pascal (Pers. C.) | floppy or cassette | > 8K | NO | Built-In Language Specific | > \$600 | 10% |

In this table, we list representative computer and operating system environments and some of their characteristics. The approximate cost column gives a ballpark number for the minimum reasonable system in the class listed. In almost every case there are three options for laboratory interfacing to developmental hardware: RS-232C asynchronous serial data transmission, the IEEE-488 General Purpose Interface Bus (GPIB), and the ever-present option of custom parallel or serial output from nonstandard ports. The more robust the computer system, the more useful it will be in the development process.

Editorial

tors in the control algorithm.

In order to generate and manipulate our program models, we need some form of text preparation system. This is sometimes an integral part of the language environment, sometimes an independent entity. In addition to the essential program text preparation tasks, a facility to do documentation is essential. Whenever more than one mind is involved with a project, thoughts must be communicated. Even if you operate as an isolated tinkerer and inventor, you'll waste time in the long run if you simply rely on memory without notes. The tools of word-processing programs, running in the software development system, meet this essential requirement.

Comparing Typical Software Tool Environments. The kinds of computer environments available for use in today's world of robotics engineering are summarized in table 1. In this table, we've listed some of the salient points about several operating environments.

On the left is listed the operating system environment, which sets the flavor for the whole development environment. The typical hardware environment specification is shown as a combination of mass storage and main memory figures. Within each environment, the column labeled "choice of languages" indicates whether or not the typical implementation gives flexibility in this key part of software development by offering multiple options. The "editors" column refers to the existence of generalized text editors for program preparation and documentation. If "YES" is noted, one or more text editors is available as a standard part of the system. Otherwise, the notes included cover the standard program preparation editing method. A ballpark cost for getting started with the system concept involved is shown based on current technology as of this writing (March 1982.) Finally, a subjective "degree of refinement" column is provided. A 100% rating indicates that in my opinion the system is ready to go with no software engineering required. A low rating indicates that in order to achieve this type of system, considerable detailed software engineering will need to be accomplished in the present state of product technology.

We start the table with a summary of current artificial intelligence machine technology. There are basically two ways to accomplish a LISP environment outside the research laboratory. One way is through purchase of a dedicated LISP machine, such as those manufactured by Symbolics or LMI. Another way is

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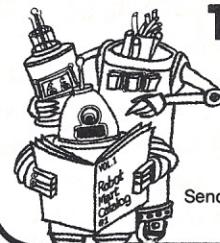
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Editorial

to purchase a microcomputer upon which LISP software is then installed. The model implied for this latter approach is a package such as John Allen's TLC LISP running on a Radio Shack or Cromemco system.

Four flavors of general-purpose personal computer software environments are listed in this table: two variants of UNIX, CP/M, and the UCSD p-System. The UNIX environment, available originally on large PDP-11 minicomputers is now becoming available on many microprocessors. This operating system is widely used by professional software engineering people. The CP/M operating system is easily the most widely used operating system of the personal computer world. CP/M is somewhat simple, somewhat machine dependent, and limited in scope. All these factors undoubtedly are reasons for its success. The UCSD p-System is the first truly machine independent software system, running the same virtual machine emulation on every major microcomputer system. Its language of implementation is UCSD Pascal. (The line in the table refers to the conventional USCD p-System implementations. At the 1982 West Coast Computer Faire, Texas Instruments demonstrated the least expensive complete UCSD Pascal system in the form of a version of the 99/4 home computer with one disk drive, priced in the \$1200 range.)

Low-cost robotics development environments

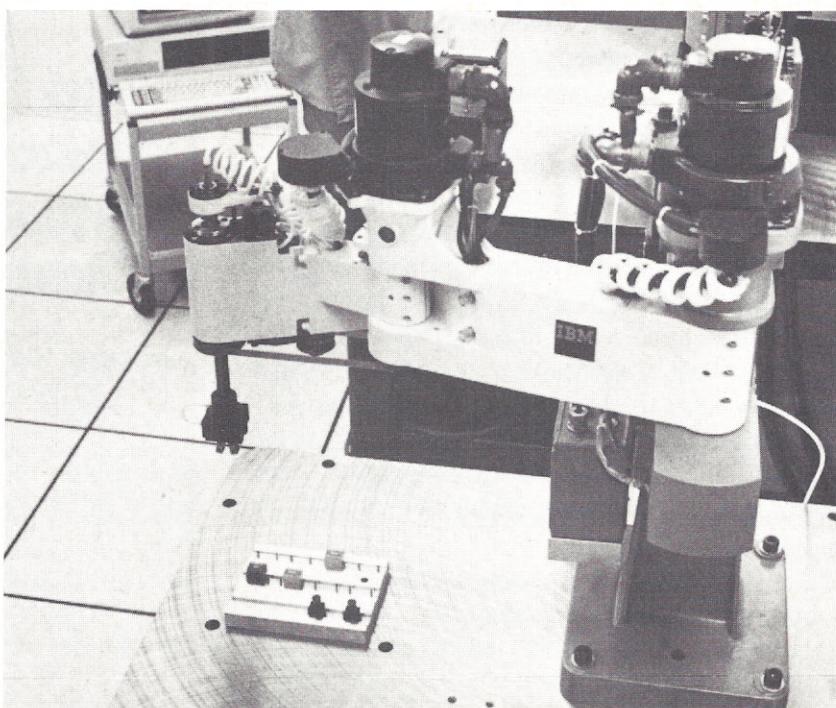
operating in single board computers and personal computers finish out the table. A typical FORTH system will run in a single board computer, giving it a flexibility and usefulness comparable to many of the larger, more expensive systems. The most primitive (and difficult to use) system concept listed here is that of a single board computer without a language system environment. While quite applicable as targets of software development on robust machines, manual programming without software tools is guaranteed to waste great amounts of time.

The final line of the table is devoted to a concept that has not yet been seen in the form of widely used products. This is the idea of a low-cost personal computer used with a built-in software system for an interactive subset of the C or Pascal languages. (C is the implementation language always available in UNIX environments.) This kind of bare bones modern language software development facility can be installed in an inexpensive personal computer if some work is devoted to the project.

As can be seen by this summary, the development environments available in the contemporary computer field present a wide range of options. Whatever the choice, the modern computer is an essential tool for the development of robotic systems. We'll continue on this subject in future commentary. □

We recently received word of an interesting and significant product introduction in the field of industrial robotics: the new IBM Model 7535 Manufacturing System, a programmable manufacturing work station.

The IBM robot uses the new IBM Personal Computer as a subsystem for control and software development. This one product illustrates the essence of the relationship of modern robotics and the personal computer: the new field of robotics stands on the shoulders of previous advances in the computer field. Without the modern single user computer, of which the personal computer is the outstanding example, many of today's ideas in robotics engineering would be much more difficult and expensive to implement.



Book Review

Brains, Behavior & Robotics

REVIEWED BY PAUL HOLLINGSHEAD

Brains, Behavior, & Robotics

by James S. Albus
BYTE Publications Inc., 70 Main St., Peter-
borough, New Hampshire, 352 pages,
\$16.95, ISBN 0-07-000975-9

What is thinking? How does our nervous system control our behavior? How can we simulate these processes for better understanding and duplicate them for use in machinery? In *Brains, Behavior, & Robotics*, Dr. James Albus tackles these tough questions and provides some good answers.

Philosophers have been trying to fathom the meaning of the terms "mind" and "thinking" for centuries, but have yet to succeed. In the beginning of *Brains*, Albus examines these terms, applying them to the example of buying a record at a shopping center, and showing the enormous amount of computation required for even such everyday tasks.

Brains. The next three chapters discuss our built-in organic computers. If you thought all nerve cells were pretty much alike, then you're wrong. Albus describes the various neuron types that have evolved to serve different purposes. Photographs taken with several types of cell staining techniques illustrate the text, and several paragraphs and diagrams discuss the clever chemical process used by nerve cells to transmit impulses.

All of this builds to an explanation of how different cells provide the sensory inputs that link our brains to the outside world. In addition to the nerves that send messages we are conscious of, many impulses carry information we never think about. A large por-

tion of the chapter describes how the eyes and ears convert information to nerve impulses.

These various nerves carry signals to and from the central nervous system. Albus shows how the signal processing becomes increasingly sophisticated as the information travels from the spinal cord up to the cerebral cortex. A map illustrates how sensory input and motor output for various parts of the body is concentrated in specific regions of the cerebrum, and numerous diagrams show different parts of the nervous system, often with a detail that exceeds the discussion in the text.

Behavior. A layered system, or hierarchy, is presented as an appropriate way to simulate the mechanism that controls our behavior. Following a review of vector notation, n-dimensional space, and operators, the fifth chapter combines these concepts to model such a hierarchical control system. At each level, modules break commands down into subcommands using feedback. Sensory information is combined, filtered, and compared with expectations at every level to generate the feedback. Predictions come from another module, which compares the commands at that level, previous similar experiences, and sensory information from other parts of the brain.

One of the most interesting sections of the book is the discussion of the Cerebellar Model Arithmetic Computer (CMAC). The CMAC, a mathematical simulation of the information processing taking place in the cerebellum, uses three different schemes for mapping one vector to the next, and thus is capable of learning and generalizing, important processes for achieving useful behavior.

Higher functions of the brain can be modeled with combinations of CMAC's, as

explained in the last chapter on behavior. The CMAC's are suitable for use as the modules in the hierarchical control system, and for use in a locked loop to recognize rhythms. Albus explains that understanding can be thought of as an increasingly sophisticated set of rhythms. Writing, speech, choice, normalcy, belief, faith, and creativity are topics in an intriguing discussion that closes out the section.

Robotics. A survey of robots from 1496 to the present documents the progress so far and the challenges that lie ahead. Several ingenious cam-driven puppets made in Switzerland during the 18th and 19th century are pictured, along with famous (and one infamous) research projects from the more recent past. Details are given about the author's project, which involves the use of structured lighting to solve the tricky and important problem of "seeing" objects placed on a table.

The next topic is the application of the hierarchical control system discussed previously. For systems with large amounts of sensory interaction, Albus shows that conventional structured programming techniques of subroutines and macro commands are not the best candidates: state machines are more suitable. He then describes how the National Bureau of Standards has implemented such a system with a collection of microprocessors.

After a brief look at artificial intelligence and language understanding, the author takes a look at the future. The current high cost of robots hinders their widespread use, and Albus suggests making manipulators from plastic and using water as the hydraulic fluid to lower the cost. He also explains why robots found their first application in

Continued on page 35

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The news items we've read or been sent in the last few months have concentrated on the entry of large companies into the robotics field, how this will affect the market and the smaller companies which have been involved in robotics for years, and what it may or may not do for more generalized public acceptance of robots.

Industrial Marketing January 1982

"Coming to Grips With the Robot Market," by Philip Maher — The robotics revolution — is it here? Marketing sources in the field think so, and they see GE Corporation's entry into the field as the start of something big. IBM and Texas Instruments are next expected to enter the race. These are big companies with big names — an impressive force to challenge the ever-widening market for robots.

This article poses the question: "can the smaller, technical-minded companies in the field compete?" The market is steadily expanding — it's no longer limited to the auto industry, thanks to breakthroughs in technology and prices. But what combination of marketing strategy, technology or other factor will keep the big-name newcomers from sweeping the smaller, long-time robot manufacturers out of the running?

No one is really sure of the answer to this question, but market analysts and robot specialists have a few ideas. Marketing is the clue to success, and marketing has only a little to do with big names. Seven essential ingredients to a successful robot marketing strategy were recently presented in a report to The Institutional Investors Conference: customer support, research and development, software enhancements, knowledge of the factory environment, marketing strength, financial strength and reputation.

Most robot manufacturers are con-

centrating on specializing in one area of the seven ingredients. Experience, service and cost seem to be the big areas of concentration. But those alone won't be enough to make robotics a big-paying industry.

Above all, consumer education is important. Education about what to expect from a robot, how to find the right robot for an application, and the knowledge that the use of robots means increased productivity and increased productivity means more jobs is essential to the continuing growth of the market and acceptance by consumers.

Iron Age January 22, 1982

A story in the "Machine Tool Newsfront" quotes representatives from the automobile industry on robotics. According to GM, Ford and Chrysler representatives, robots and car manufacturing are not synonymous.

Manufacturers find the high cost of robotic automation to be prohibitive. Engineers are not easily able to conceptualize how to produce a product with robots; robots don't fit into existing systems easily. Chrysler, for instance, tends to use robotic processes only where new product production is planned for them.

According to this article, all too often, robotic automation costs too much. Manufacturers are reluctant to spend large sums of money to try an application which may not work or fit into existing systems.

The Boston Globe

The *Boston Globe* recently reported on the development of a generation of intelligent robots, in an article by Donald Kirk. According to the *Globe*, Japanese government and manufacturing officials are diligently working on robots which

can see, hear and touch, in a robot sense of the words, of course. These robots will be so accurately programmable that they will be able to inspect fine products, take part in production of small parts, and detect trouble in nuclear power plants. According to the *Globe*, the Japanese expect this new generation of robots to put them far ahead of US manufacturers in robotics technology.

The Japanese have 2000 intelligent robots now, and they are used mostly on assembly lines. Even these do not have the capabilities needed to assemble machinery. For this chore, a flexible robot, resembling a human being, is necessary. Research hasn't developed to the point where that technology is a likelihood in the near future.

It may be 10 years or more before robotics has developed to that fine point, but it is moving inexorably in that direction.

Business Week March 8, 1982

Artificial Intelligence (AI) is a term used to describe a computer system that mimics human thought processes. Through the development of AI technology, computers and robots can be made to perform tasks that we have always believed require human intelligence.

According to the *Business Week* report the development of AI systems are currently culminating in several applications: computers which can act as automatic experts, computers which understand everyday English, either written or verbal, and computers which use sensory input — particularly artificial sight and hearing — to guide robot arms.

Computers are being taught to think and react as a human being — to store huge banks of rules, facts and methods of problem solving, and to process them immediately, and as humans do — allowing for those grey areas between ab-

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solutely right and absolutely wrong, or to take into account variations on the information programmed into the system.

What does this mean to the robotics community? Many things: AI vision systems coupled with intelligent software will create robots which can determine that some sensory input is unimportant information and ignore it. It will allow the same robots to produce different products on different days without extensive hardware or software modifications. The software that runs robots will "learn" from its activities.

Again, according to *Business Week*, the Japanese are in the picture. Right now, US researchers and companies are at the forefront of AI development. The Japanese government, however, will spend \$45 million to begin research and development — hardware design and advanced software — on a new generation of computers which are meant specifically for AI applications. The Japanese expect AI applications to head the market in the next decade, and they want to be in control of that market.

Business Week February 8, 1982

An article in *Business Week*'s International Business section reported on the sale of robots to the USSR and other Communist bloc countries by US manufacturers and their licensees.

According to this article, the Russians have stated that they will require 50,000 robots in the country by the end of the decade. The Russians and East Germany and Bulgaria are manufacturing robots. So far, according to *Business Week*, the Russians have made between six and seven thousand. These are mainly nonprogrammable manipulating machines.

A US manufacturer, Unimation Inc., and its Japanese licensee, as one example, have been selling high-tech robots to the Soviets. Already over 100 of its robots have found their way to Com-

munist bloc countries, and the US manufacturer is gearing up its licensees to do a booming sales in the next few years.

The robots sold to the USSR are meant for manufacturing, but contain hardware and software technology that could be used for other purposes. The sales are not opposed by the US government, despite bars on exports that could aid the Soviet military power.

Datamation February 1982

'Pushing the State of the Art,' by Jan Johnson — There's an organization of 144 large manufacturers (Boeing, Computervision, Fujitsu, Lockheed and Westinghouse are a few) based in Texas

which is trying very hard to direct the future of CAD/CAM. The organization is called CAM-I (Computer Aided Manufacturing — International, Inc.), and it plans to have designed the ideal factory — one which is designed, simulated on and operated by computers — in the next few years. It expects to spend \$1.55 million by 1985 in this pursuit.

CAM-I will do this through a generalized geometric modeling system. The companies involved pay a yearly membership fee which may be directed towards a specific project or used generally. Six projects are currently under way.

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working on the projects, as well as the future benefits of involvement in developing a system which couldn't be designed or afforded by any one company.

An example — computer animation can be used to simulate robot performance. New control languages can be tested, new robot applications simulated, strengths and weaknesses determined and ironed out without investing in the hardware, an often costly experiment.

CAM-I aims at an integrated factory technology of this sort throughout the factory and on all levels of factory operations.

Datamation

A recent news release from *Datamation* magazine reports that within 10 years, eggs will be inspected by robots, which will also spray insecticides, spread fertilizer and pack produce. Submarine robots may be used to build fish farms and explore the ocean floor for mineral deposits.

The Japanese robot manufacturers are in the forefront of this technology of using robots for applications other than manufacturing. The Japanese Industrial Robot Association expects sales for non-manufacturing robots to be near \$360 million by 1990.

American Metal Market/ Metalworking News

February 1, 1982

A report by Al Wrigley shows Bendix Corp. to be the newest large manufacturer to move into the robot manufacturing field with the introduction of its AA Series and MC Series of robots.

The AA Series are computer numerically controlled, can carry 45 pounds, rotate at 170 degrees per second with barrel roll and yaw/pitch speeds of

200 degrees per second. Vertical reach is 102 inches, horizontal reach is 60 inches. The robots are able to bend over backwards, permitting a wider application in a small space, and let robots reach objects off-line.

The MC Series is larger, developed last year, and several units are currently in use at the Chevrolet Motor Division of General Motors Corp. in Tonawanda, NY. MC units have a 158-inch vertical reach, 98-inch horizontal reach and may rotate 300 degrees, reaching a very large work area.

American Metal Market/ Metalworking News

February 1, 1982

“Robot Venture Launched,” by Al Wrigley — Arrowsmith Corp. of Michigan, a corporation holding Premier Industries as a subsidiary, has started Automation Corp., to manufacture and design a new line of robots. Automation will operate as an affiliate of Marathon Industries, itself a division of Premier Industries.

Automation Corp. was recently scheduled to show its robot line, Automaton, a hydraulically powered, two-armed, medium priced robot. Automaton is designed for sequenced mechanical motions, to be used alongside human operators on stop-and-go transfer systems.

Automation has also been licensed to manufacture Automated Systems Engineering Co.’s Programmable Loading and Unloading Machine (PLUM) robots.

Commline

January-February 1982

“Management Resistance to Industrial Robots,” by Neale W. Clapp — Often robots fail when they are introduced into a new factory or for a new applica-

tion not because the robot was wrong for the job, but because the social systems of manufacturing are not capable of dealing with the interpersonal and interdepartmental changes and problems that automation brings with it. If these systems are changed, if supervisors and all levels of management are aware of what to look for, how to deal with it, and are agreed on costs and benefits the introduction of robots will make to the company, the problems may be nipped before they bud, or not arise at all.

Robot applications are threatened by management resistance; the workplace social system is rarely examined. Resistance is usually seen as coming from the worker and the Unions. Clapp looks at the less obvious, non-verbalized problems caused by the rapid growth of robot applications, and ways to solve those problems.

The Christian Science Monitor

March 5, 1982

A recent article by David T. Cook comments on the expected results of the influx of large and small businesses into the robotics manufacturing field.

Until recently, Unimation Inc. was the largest manufacturer in the field, with sales of \$57 million last year. Entire robot sales for 1981 were \$151 million. This is expected to change radically, starting this year.

In 1982, robot sales are expected to hit \$215 million, and increase by 35 percent per year through 1990. There are about 50 robot makers, large and small, looking for a share of that market.

IBM Corp. is a recent entry into the field, joining Westinghouse, General Electric and Bendix Corporations. While the size and marketing power of these large newcomers can't be ignored, they should help the market as a whole. They have the marketing power to tap

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the export robot market, curbing Japan's lead. They will spur the acceptance of robots and industry sales in this country. They also will push robotics technology to new heights through research and development, opening new fields for robotics applications and bringing the price of robots down to a more affordable level.

It is interesting to note that most of the large companies entering the field have licensed the technology for their robots, often from the Japanese, rather than develop their own first efforts.

Business Week

March 8, 1982

According to a recent article in *Business Week*, the Royal Dutch/Shell Group and Exxon Corporation have designed a unique device for underwater oil drilling that uses robotics as a main

part of its functioning.

The device is called an underwater manifold center (UMC), and is used as a template through which an oil drilling ship can drill and pump oil, from depths heretofore unreachable by contemporary drilling methods.

The UMC is directed by a TRW Ferranti Subsea Computer system and uses a rebuilt General Electric Co. robot. It can operate valves, repair damaged parts and change well functions at depths up to 5000 feet. The maximum working depth for divers is 900 feet.

The UMC will be tested in May in the North Sea at a depth of 1000 feet.

The New York Times

March 4, 1982

Home robots that do storybook jobs such as handle delicate wine glasses

without crushing them do not exist in today's technology. They are not impossible; according to Carl Helmers, Editor of *Robotics Age*, he could build one for \$100,000. It wouldn't be perfect, however, and there aren't many people who could afford such an expensive, roving drink dispenser.

More typical of home robots is Avatar, a robot currently being perfected by Charles Balmer. Avatar is unique in that it is not radio-controlled, as many "showbots" are, but is a true robot, capable of manipulating its way around a house without bumping into things (for more on Avatar, see *Robotics Age*, January/February 1982 issue).

Large corporations are researching the possibilities of home robotics. Perhaps the most promising application for home robots will be in medical applications, where robots make up for the physical disabilities of handicapped persons.

Classified Advertising

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PART SOURCES FOR ROBOTS

The following is a partial list of robot parts sources. Please keep these points in mind when considering any surplus parts.

1) Surplus parts disappear! If you design around a surplus part don't be surprised if you have to junk your work because repair parts or replacements are no longer available. It may pay to buy three or four spares.

2) Never assume anything. If a description says AC powered, don't assume that means 110 V, 60 Hertz. It *could* mean 26 V AC, 400 Hertz, or some other combination. The good companies tend to answer questions, so write or call.

3) Avoid the "I may need it someday" trap. Buy only if you are 100 percent sure it is what you need now.

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Quincy, IL 62301
Magnetic field detectors.

Small Parts Inc.
6901 N.E. Third Avenue
POB 381736
Miami, FL 33138
Metal stock, plastic gears, fasteners, pulleys, bearings.

Mountain West
Box 10780
Phoenix, AZ 85064
(602) 263-8831
12V DC fire detectors, ultrasonic units, passive infrared detectors, tape switches.

Brookstone Company
127 Vose Farm Road
Peterborough, NH 03458
Wind-your-own-spring tool, plasti-dip, hand tools.

Poly-Packs
POB 942
South Lynnfield, MA 01940
Electronic parts.

United Detector Technology
3939 Landmark Street
Culver City, CA 90230
(213) 204-2250
Photocells used in passive infrared people detectors.

Lindsay Publications
POB 12
Bradley, IL 60915
Hard-to-find books on many subjects, mostly technical, batteries, hydraulics, machining, design.

Herbach & Rademan Inc.
401 East Erie Avenue
Philadelphia, PA 19134
(215) 426-1700
Mostly mechanical surplus, some small electronic parts.

Jerryco Inc.
5700 Northwest Highway
Chicago, IL 60646
Surplus, all kinds, mostly mechanical.

United States Robotics Society
616 University Avenue
Palo Alto, CA 94086
Newsletter; haven't heard from them in ages!

David Smith
4505 Kennedy Boulevard
North Bergen, NJ 07047

Browning Power Transmission Equipment
Emerson Electric Company
Maysville, KY 41056
(606) 564-2011
Bearings, universals, etc. Flat-Veyor chain would make a tread and the Extended Pitch Chain would make a good finger (android design).

McMaster-Carr Supply Company
POB 4355
Chicago, IL 60680
Cable, roller chain, hinges, metal hose, duct hose, couplings, tools.

Plasti-Dip International
1458 West County Road
St. Paul, MN 55113
(612) 633-9633
Or local hardware store: air dry flexible plastic coating.

Digital Research: Parts
POB 401247
Garland, TX 75040
(214) 271-2461
60/100 Hz timebase kit, small parts.

Solid State Sales
POB 74
Somerville, MA 02143
(617) 547-7053
Laser diodes, small electronic parts.

LS Engineering
Canoga Park, CA 91305
(213) 992-1827
Ultraviolet EPROM eraser.

Jade Computer Products
4901 West Rosecrans Avenue
Hawthorne, CA 90250
Systems, S-100 boards, ultraviolet EPROM eraser, small parts.

Information Unlimited or
Scientific Systems
Box 716
Amherst, NH 03031
Plans, kits, laser plans and parts, high-power ultrasonic parts and plans. Important note: some of the units and plans listed in this catalog can deliver enough power to injure.

Rondure Company
2522 Butler
Dallas, TX 75235
(214) 630-4621
Electronic units.

Surplus Center
1000-1015 West "O" Street
POB 82209
Lincoln, NE 68501
(402) 435-4366
DC motors, large hydraulic parts, tools, battery chargers, welders.

Systems Control
30 Thirsk Road
North Yorkshire, DL61PH, England
Phone: 0609 70643
Complete robot arms.

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POB 338
Redwood City, CA 94064
(415) 367-1137
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kit, solid state switch, 6502 microcontroller card,
solid state dimmer.

Chaney Electronics Inc.
POB 27038
Denver, CO 80227
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small mike, other electronic parts.

Jameco Electronics
1355 Shoreway Road
Belmont, CA 94002
(415) 592-8097
+ 5 V DC to other DC voltages kit, small elec-
tronic parts, keyboards, cables and jumpers, proto-
type breadboards.

Edmund Scientific
101 East Gloucester Pike
Barrington, NJ 08007
(609) 547-8900
Optics, tools, parts.

Dal-Comp
2560 Electronic Lane
Suite 108
Dallas, TX 75220
(214) 350-6895

Parts, computer systems, prototype circuit cards,
cables, wire wrap products.

Vector Electronic Company Inc.
12460 Gladstone Avenue
Sylmar, CA 91342
(213) 365-9661
Vectorboards, prototype cards, card cages,
connectors.

Measurement and Control News
2294 West Liberty Avenue
Pittsburgh, PA 15216
(412) 343-9666
All kinds of equipment for industry. Some units
could be used in a home robot. Also good for
ideas.

Moudy Electronics
R.D. 2, Box 427
Hollidaysburg, PA 16648
Newsletter, robot parts catalog; haven't heard
from them lately.

The Robot Mart
19 West 34th Street
New York, NY 10001
Robot parts, newsletter, only retail robot store I
know of.

Snyder Electronics Inc.
2082 North Lincoln Avenue
Altadena, CA 91001
Tape switches, pressure mats.

International Robotics Foundation
3011 Community Avenue
La Crescenta, CA 91214
Newsletter; haven't heard from them lately.

Hobby Robotics Company
Box 997
Lilburn, GA 30141
Robot kits, newsletter.

Stand Surplus Center
2202 Stand
Galveston, TX 77550
Catalog \$1, all kinds of army surplus.

Hardware Products Company
84 Fulton Street
Boston, MA 02113
Springs, all kinds.

Cadillac Plastic
POB 810
Detroit, MI 48232
Plastics, all kinds.

Consolidated Wire
1635 South Clifton Street
Chicago, IL 60616
(312) 421-4441
Electronic wire, cable.

Yuasa Battery Inc.
8108 Freestone Avenue
Santa Fe Springs, CA 90670
(213) 698-2275
Sealed lead-acid batteries.

Arrowhead Enterprises Inc.
Anderson Avenue
New Milford, CT 06776
(800) 243-7852
(203) 354-9381
Passive infrared detectors, ultrasonic intrusion
detectors, 12 V DC operated.

Semiconductor Circuits Inc.
49 Range Road
Windham, NH 03087
(603) 893-2330
DC to DC power supply converters.

Rainbow Industrial Products Corporation
53-23 Metropolitan Avenue
Flushing, NY 11385
(212) 366-8600
Roller chain.

Ace R/C Inc.
Box 511
116 West 19th Street
Higginville, MO 64037
Radio control parts, transmitters and receivers.

Vantec
15445 Ventura Boulevard
Suite 10-281
Sherman Oaks, CA 91413
Radio control add ons.

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Riverdale, NJ 07457
(201) 835-0882
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□

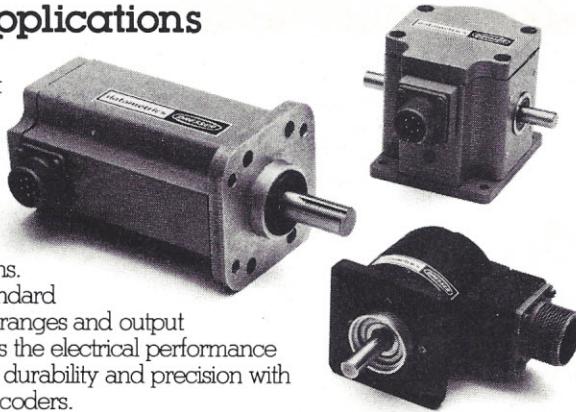
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AN INEXPENSIVE ARM-HAND SYSTEM

Mark J. Robillard

3 Peach Lane

Townsend, Massachusetts 01469

The other night I watched in amazement the actions of a university robot on a local PBS television show as it carefully stacked blocks according to alphabet markings. Beginning robotics can be so frustrating!

Beginning anything is hard. How to get there from here? It seems so far.

My frustration usually drives me to create. This time it drove me to construct a usable robot arm. All you need is a tolerance for disappointment, a four-function calculator, and approximately \$50 to \$60. What you get in return is a functioning arm capable of lifting a few pounds, and a complete wrist-hand assembly with two degrees of freedom (see photo 1).

Let's start with a very basic arm with attached wrist and hand. With this combination you can not only experiment with programming, but gain experience with motor control circuits. And when you've completed this first step, you'll have a machine that will be capable of acting alone, without a motorized motion platform.

The arm holds most of the fascination of robotics anyway. You can spend hours programming it to fetch objects and stack them. Add intelligence, and maybe you could reproduce the experiments that are going on in universities across the country.

A brief review of the capabilities of the human arm reveals that there are

three basic joints, providing almost 27 degrees of freedom. We won't attempt to emulate all this, but we can achieve forward and back and two degrees of freedom in the wrist of pitch (up and down) and roll or rotate. The hand will also open and close.

The subject might sound familiar if you read my article in the last *Robotics Age* (March/April). This time the clasp mechanism will approach that of a human. Photo 2 shows the complete wrist-hand assembly. Looks ominous doesn't it?

Three motors and small pieces of wood make up the entire construction. Wait — I forgot the two pieces of aluminum supporting the knuckle assembly (which could also be fashioned out of wood: I just decided to get fancy).

Drive. The motors are very lightweight plastic high torque gearhead units from Edmund Scientific that are geared down to provide more power for their size. According to the catalog, they are rated as having "31 ounce-inches" of "stall torque." To the uninitiated, this indicates the output power rating. Following the tradition of amp/hours and volt/ampères, ounce-inches is a way of expressing just the opposite of what it sounds like.

Ounce-inches is a measure of torque. Torque is force that produces motion, in this case, about an axis of rotation (the motor shaft). Torque is the dimension of force multiplied by distance.

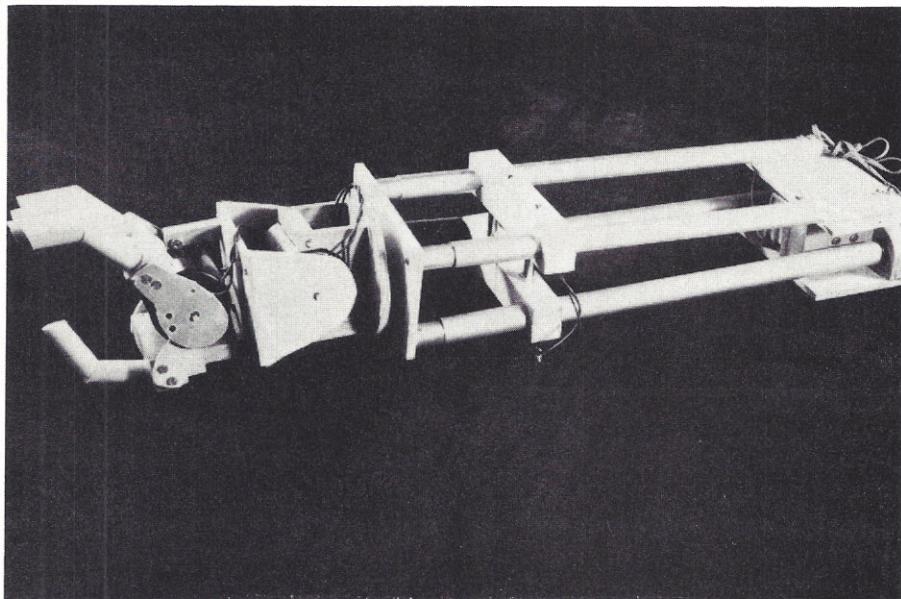


Photo 1: The complete hand-arm system.

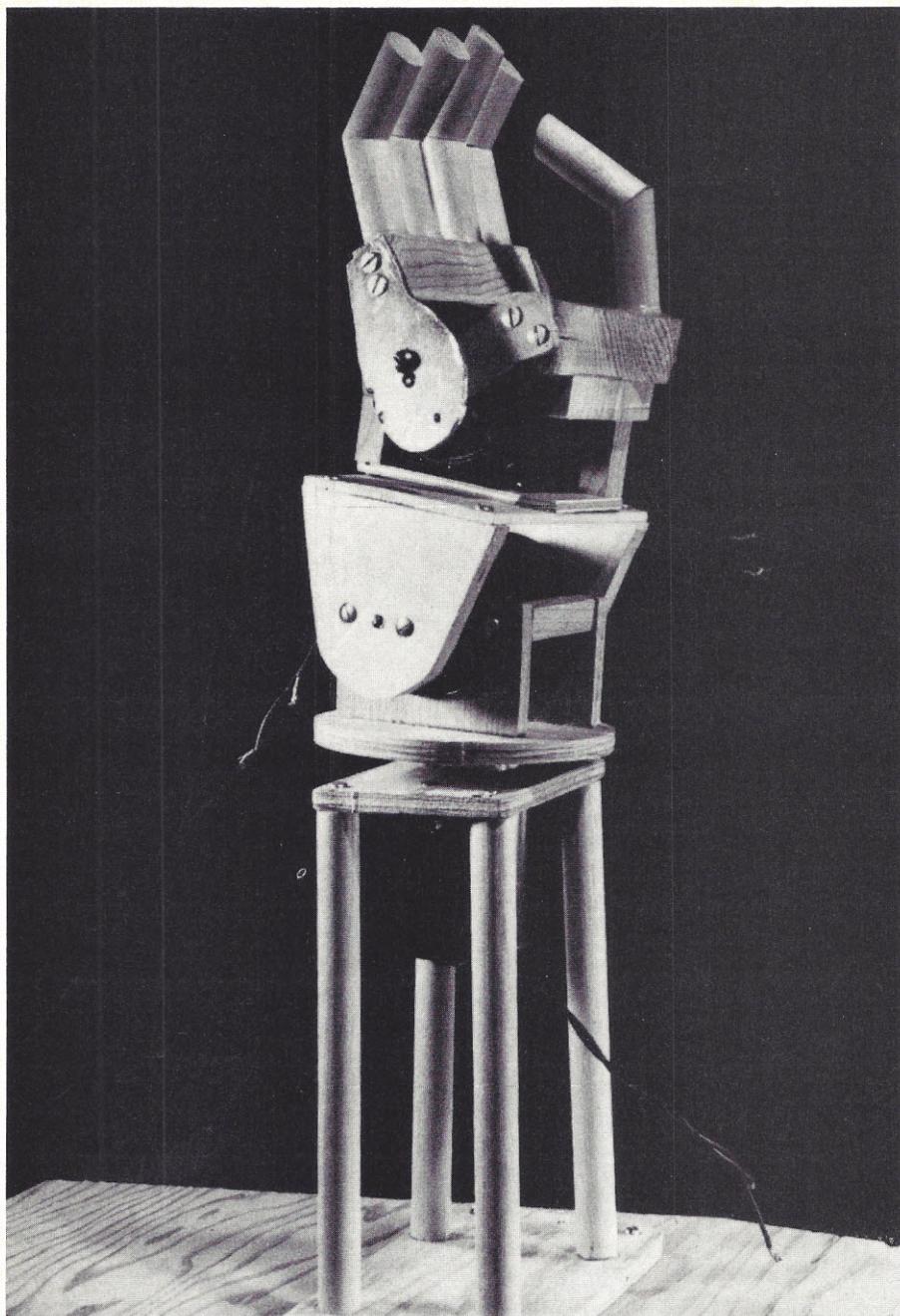


Photo 2: Hand-wrist unit fully assembled.

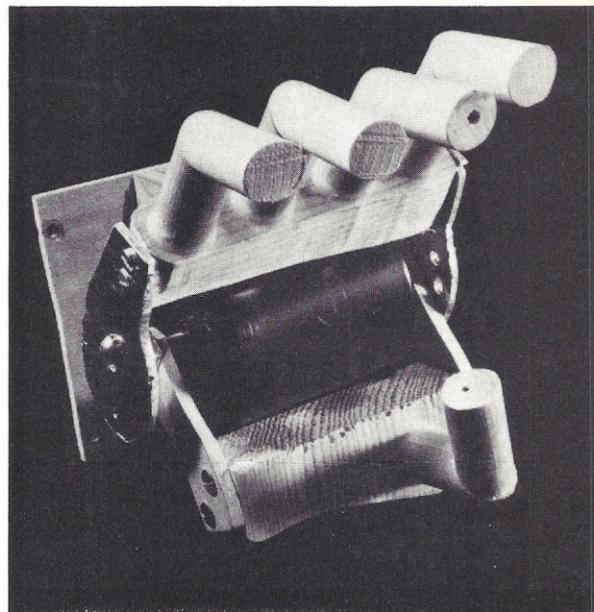


Photo 3: Hand reaching for freedom. Internal construction techniques can be seen.

Motor, Torque, and Force

$$\text{Payload Weight} \times \text{Distance to Travel} = \text{Torque Required} \times \text{Number of Revolutions of Gear to Move Distance} \times 2\pi$$

Example:

$$\begin{aligned}
 5 \text{ pounds payload} \times 10 \text{ inch distance} &= T \times (200 \text{ revolutions} \times 2\pi) \\
 50 \text{ pounds-inch} &= T \times 1256 \\
 50 \text{ pounds-inch} &= T \\
 1256 & \\
 0.63 \text{ ounces-inch} &= T
 \end{aligned}$$

The product of these entities is stated in measures compatible with the units used. As an example, a 1-ounce force pushing (or pulling) an object from a 1-inch rod mounted perpendicular to the force is said to have one ounce-inch of torque.

$$\text{Required torque} = \text{Force} \times \text{Distance to motor shaft}$$

The motors I purchased were also said to have a rotational speed of 2 rpm, which means the shaft will make two complete revolutions each minute. This

unit of measure is important to remember if you are going to be "gearing down" or speed reducing the motor. You could end up with a hand that closes completely in one hour!

If you happen to have a box of motors somewhere in your workshop, and you'd like to know what kind of torque they will pull, there is a fairly simple method for finding out. First you will need a pulley for the shaft. If you don't have one, you can either make or buy one. Should you decide to make one, keep in mind that the radius of the pulley is used in the torque formula so make it a simple even number. Next find some string and something to put a weight into, like a pail or a paper cup. Connect the weight holder to the string and the string to the pulley. Firmly attach the motor to a workbench using a vise or C-clamp (see figure 1). Increase the weight in the cup until the motor stalls, then multiply the weight of the cup and its contents times the radius of the pulley (measure the pulley in inches and the weight in ounces) and you will have the rated torque of your motor in ounce-inches.

Structure. The hand shown in photo 3 is built of wood dowel pieces cut at different angles and inserted into a wood block fashioned after the knuckle area of the hand. This part is the only portion of the hand that actually moves. The thumb and palm subassembly is fixed. I chose to mount the motor directly in the palm area. The shaft is directly fastened to the movable finger assembly. After construction you have a hand unit with 31 ounce-inches of torque that closes at the rate of 2 rpm or 0.5 inches per second — about as fast as you close your hand.

What else can be done with the hand?

You can add some sensors; maybe develop some type of pressure feedback system. Some university researchers are working on a synthetic skin that uses thin sheets of rubber (surgical gloves?) with tiny (30 gauge?) wires embedded in them to act as a sophisticated membrane switch. Sounds like an easy thing to try.

Wrist. Tricky, very tricky. Of course you want your robot's wrist to mimic all

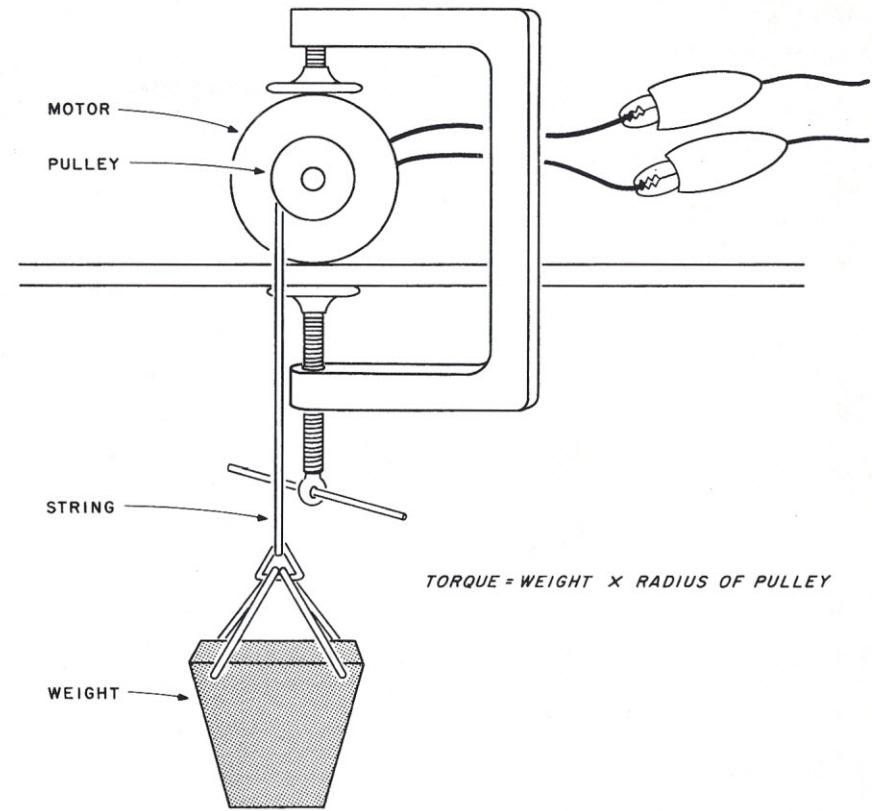


Figure 1: Benchtop torque measuring test set up.

the functions of your own, but there is a practical limit. I found this limit to be up-down and around. The "around" works great for screwing thing in with a screw driver. Unfortunately, the human system does not support this option.

The up-down, or pitch, as it is formally called, is a very straightforward application of the same design we utilized in the hand. Referring to photo 4, mount the hand to a movable platform that is fastened to the shaft of another of those handy motors.

Wrist roll or rotation is the simplest mechanism of all. The third and last motor is mounted on a plate and its shaft is connected to the center point of the plate that holds the pitch motor. Simple as 1, 2, 3 . . . (motors that is).

Now you have this monster hand. You could stop here or go on to give it mobility. In any case, build a stand for it and place it on top of your work bench, as there's no need to have it roll around on the floor yet. A working hand on a stand would make a fascinating science project for high

school students. By now you should have many ideas of your own, so let's go on to describe how you can get an arm.

The Arm. Buy an arm? Why not . . . if you've got the money. How much? Well, the general price range of robot arm kits or assembled units runs from \$500 to several thousand dollars. These are pre-engineered, so if you're not mechanically inclined this may be the choice for you. Off-the-shelf arms range from rather crude mechanical appendages to highly sophisticated manipulators. A truly low-cost robot arm has yet to reach the market, however, so if you can't afford the initial charge, forget it! Right?

Wrong! Build one from scratch!

It's really not that hard to construct a basic working robot arm. The hard part is deciding what type of arm you want. There are two easily constructed arrangements: one arm is a copy of yours and mine; the other is the telescoping kind so often seen in science-fiction movies. Both have ad-

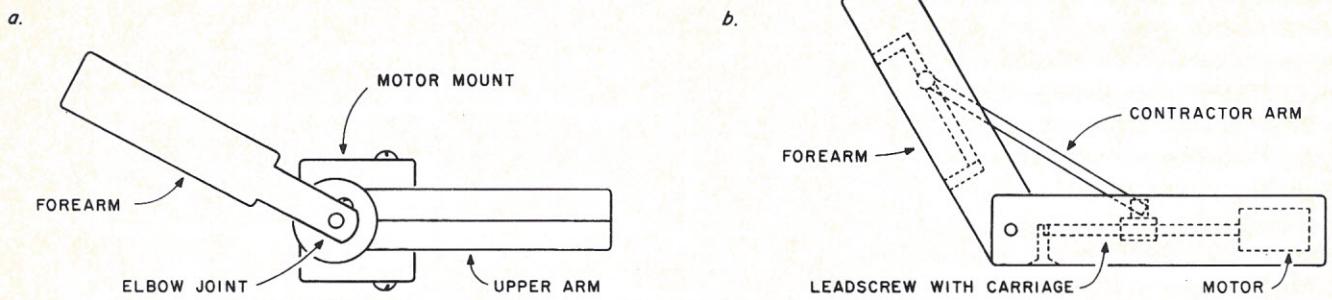


Figure 2: Two methods of utilizing a motor to provide a human-like elbow joint.

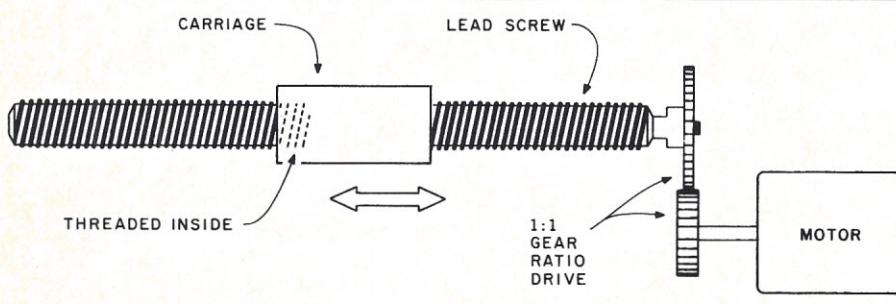


Figure 3: Lead screw fundamentals. Carriage rides revolving screw threads.

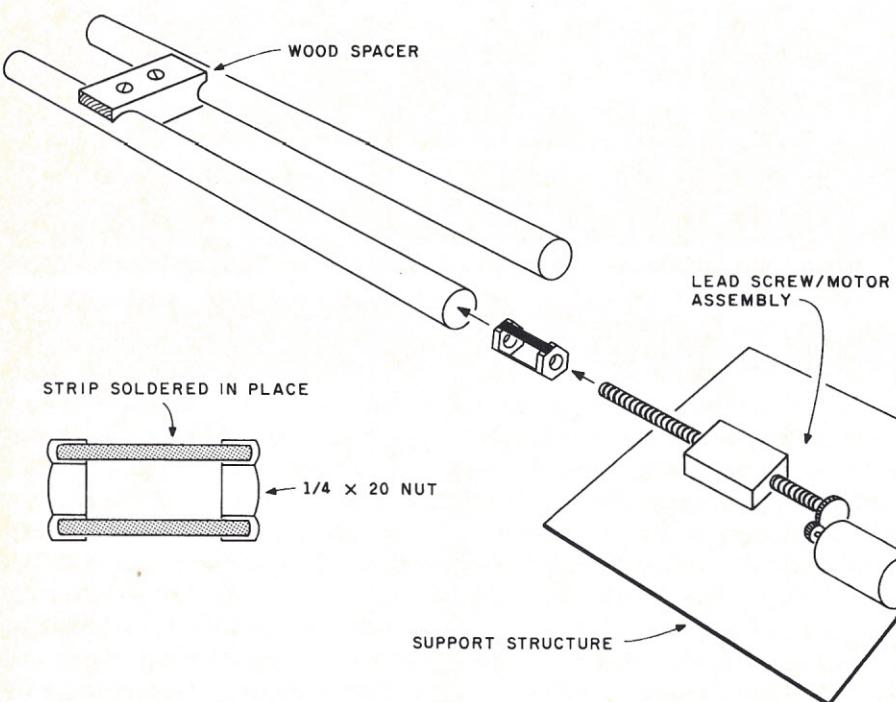


Figure 4: Details of arm construction. Carriage made of two $\frac{1}{4}$ by 20 threaded nuts held together by thin strips of metal. Also shown is the relationship between support tubes, carriage, and lead screw assembly.

vantages and disadvantages. The human-type arm must bend at the elbow, which can be difficult to emulate economically because of the power necessary to lift the lower portion of the

arm and hold it there. The telescoping-type arm doesn't have this problem, but it presents another dilemma: converting the rotary motion of a motor into the linear action of the arm.

The elbow of the human-like arm can operate by either of two methods. The first is obvious: you could put a motor in the joint of the elbow with its shaft replacing the pivot point where the forearm and the upper arm meet (see figure 2a). Depending on how much or what you want to pick up, there can be a tremendous strain on the elbow motor. Therefore, it is important to know how to calculate the amount of torque the motor needs to pick up the forearm and hand.

Let's assume that after using the formula, you arrive at a torque of 5 pound-inches. This means you will need a sizeable motor. Motors are rated in ounce-inches, so, converting 5 pound-inches to ounce-inches, it comes out to 80! A typical stepper motor rated for that kind of torque will cost in excess of \$200 unless you find a surplus motor. Even then, the motor will probably weigh a good four pounds. Think of the motor in the shoulder having to lift not only the forearm and hand but also that heavy elbow motor.

Another possibility is the use of a *contractor bar* (see figure 2b). This system uses a motor of much lower torque rating to drive a "lead screw" type gear. The bar travels the lead screw thread, effectively pulling or pushing the forearm up or down. The main disadvantage is that the arm can only open to an "L" shape and cannot close up completely.

Some arm mechanisms use belts or cables attached to gears and pulleys. Although these systems are efficient, their mechanical complexity is prohibitive. You should choose a simple approach for a first arm so that you spend more time getting to use it than building it.

A variation to the contractor bar approach would appear to be the simplest and most efficient path. Enter the telescoping arm.

It's obvious that the telescoping principle works. It is the basis of automatic automobile antennas and extendable antenna for space satellites, and you've even seen it on robots on television and in movies.

The telescoping arm moves in a linear motion, either straight out or straight

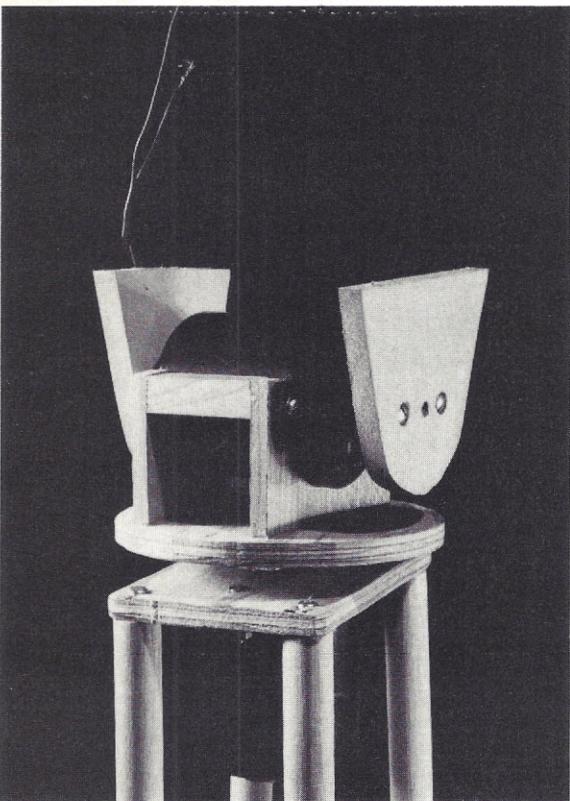


Photo 4: Wrist mechanism with hand removed.

in. This motion is accomplished by a lead screw. The drive motor turns the lead screw while the forearm shafts ride up or down the screw threads. You can observe this action by placing a nut on the middle of an ordinary machine screw and turning the screw (holding the nut from turning). You will notice that the nut will ride the screw (see figure 3).

The motor used to drive the screw can be either a stepper or a regular DC type. However, because there are many teeth on a 9-inch lead screw, position accuracy can be achieved without the use of a stepper.

Torque is still an important con-

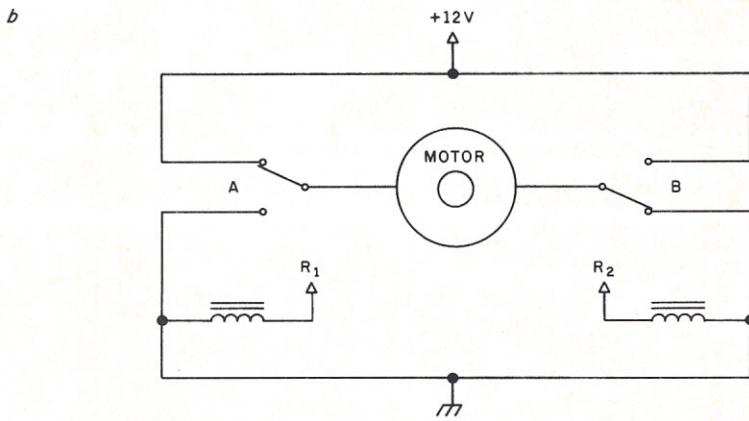
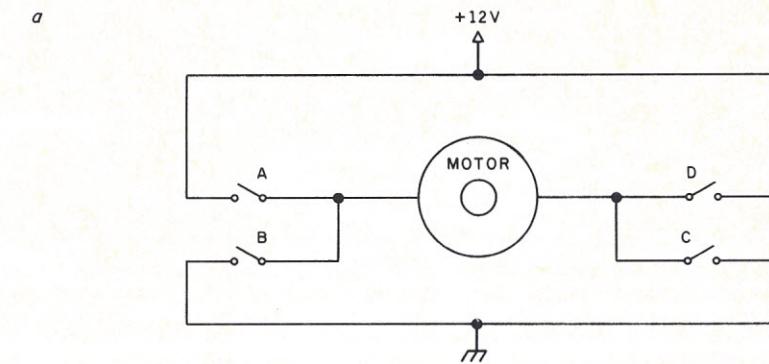


Figure 5: Basic motor control circuits: mechanical switch action (a); relay control (b); and electronic transistor control (c and d).

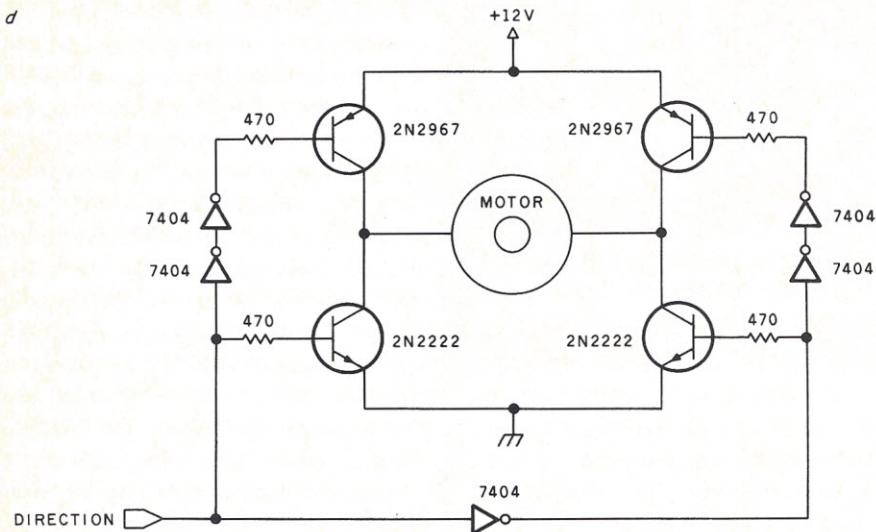
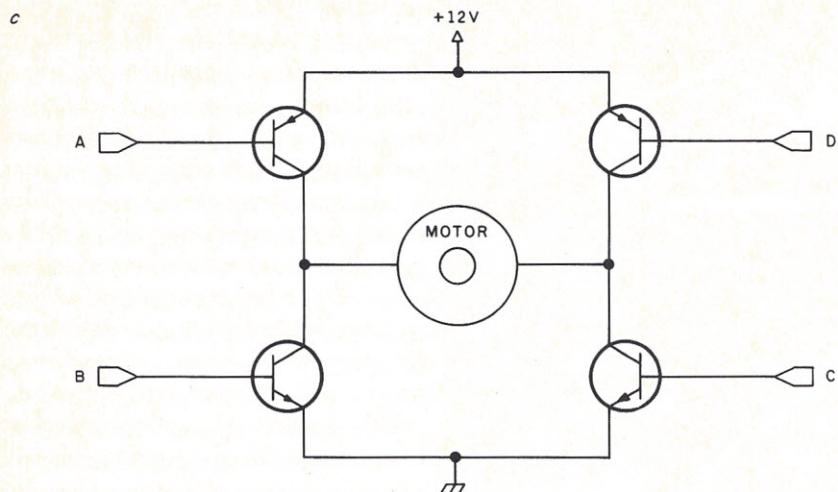
sideration, but the gear ratio between the motor and the lead screw is usually so high that a relatively small motor can move a relatively heavy weight. The formula is almost identical to the previous torque calculations in that the weight of the hand and its cargo is multiplied by the length of the forearm. The product of this calculation represents the amount of work to be performed. If the weight of the hand plus, for example, a gallon of milk, is 5 pounds, and the length of the forearm is 10 inches, the overall work to be performed is 50 pound-inches. This may sound like a lot compared to the 8 ounce-inch stepper motor you just bought, but let's see how the lead screw makes up for a lot of this work.

Looking at the lead screw equation

that appears in the textbox "Motor Torque and Force," we see the other half of the equation calls for the number of threads per inch of the screw multiplied by 2π (6.2832). This assumes that you are driving the lead screw with a one-to-one gear ratio from motor to screw. For example, if the motor driving the lead screw is attached to a gear with 20 teeth, then the lead screw driving shaft end must have a similar size gear.

Finishing the equation for the 5 pound, 10 inch example, shows that a motor with only 0.63 ounce-inches can successfully lift the 5 pound weight when in the maximum worst case position (straight down).

Enough mathematics — where can I get a lead screw? I just bought a lead



screw (a 9-inch one) with gear drive mechanics and a .65 ounce-inch motor for \$1.50! It's called a reading pacer machine (see photo 5), once used in a speed reading program and now available from many surplus outlets. Prices will vary, but I haven't seen them at much more than \$4. If you should decide to go the custom route, there are several sources for lead screws, gears, and motors (see references at the conclusion of this article).

The lead screw I purchased has a $\frac{1}{4}$ by 20 thread, so two nuts from the local hardware store and some light strips of metal make a carriage that will ride the lead screw. This carriage is used to act as a moving boat that helps extend the inner portion of the telescoping arm. The relationship between the carriage

and the support tubes is illustrated in figure 4.

Control. Now that we have a pile of mechanical parts that somewhat resembles an arm, let's make it act like one. Controlling DC motors is straightforward and there are a number of ways you can go about it.

The first method, of course, is to use switches. Figure 5a depicts the connection scheme needed to activate each motor for both forward and reverse. It is unlikely you would want to pursue this type of control, but if you study the relationship between each switch and the action each unit must provide, you will gain a better understanding of the electronic circuits to follow. A little description is in order.

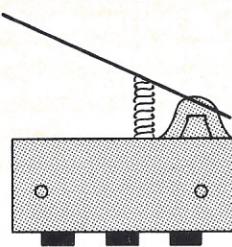
The switches in the diagram are labeled A through D. It's assumed that the motor is a 12 V type, but any voltage can be substituted. If both switch A and B are closed or connected, this would only serve to short out the power supply; likewise, for switches C and D. So, the first rule of thumb is that neither A and B nor C and D can be activated simultaneously. This leaves us with opposite pairs. If A and D are closed there is no current path to ground, therefore the motor will not operate. The same holds true for B and C. Another rule emerges — neither A and D nor B and C can be activated together.

Now we come to switches A and C or B and D. When switching between these combinations you will observe the forward and reverse action of the motor. Of course, if we want to include an overall disable switch for the entire circuit, it can be placed between the common connection of B and C and ground. This switch, when opened, would prevent the motor from operating no matter what the other switch settings are.

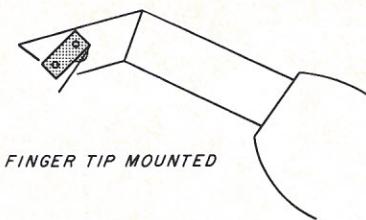
The logical progression would be to substitute the manual switch action of figure 5a with a method of electrically controlling the connections. This type of electrical switch replacement is called a relay. Relays have contacts just like the manual switches used previously, but they switch those connections with the use of an electromagnet.

Figure 5b depicts the same circuit utilizing relays. Because we now know the basic rules about switching forward and reverse, I chose to change the circuit somewhat. Notice that it is impossible to short the power supply with this arrangement. These types of switch contact arrangements can substitute for the four in figure 5a.

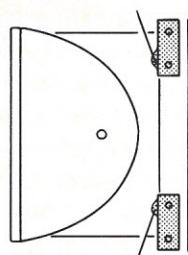
R_1 and R_2 are control voltages that activate the relay's electromagnet, which pulls the wiper arm of the switch to the lower contact. R_1 and R_2 should not be activated at the same time. Experiment with the circuit in your mind. The voltages used for the control depend on the coil voltage specified for the relay you are using. There is one more important consideration when picking the relay: the contact current handling capability. (Carrying this pro-



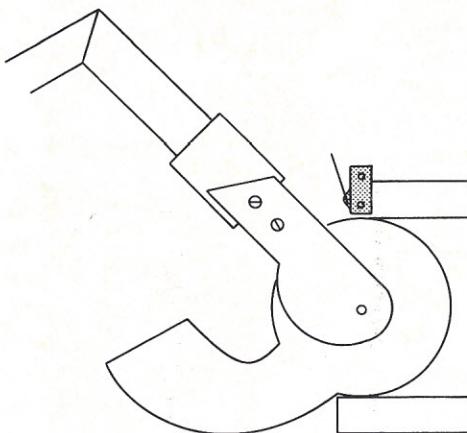
TYPICAL LIMIT SWITCH



FINGER TIP MOUNTED



WRIST SENSING



HAND LIMIT SENSING

Figure 6: Microswitches and applications for use as limit switches in the hand-arm system.

cess one step further, each relay could be replaced by a transistor.)

Power. Until now we have only concerned ourselves with the motor's torque rating and its ability to do the necessary work. In order to control this motor we have to pick components that can handle the electrical current that the motor needs to accomplish the task assigned to it. This current rating is the power the motor consumes. Most motors have the power rating or current rating stamped on the case or listed in the specifications. Power is the operating current multiplied by the voltage used. If the motor is supplied with only a power rating, you can find the current by dividing this number by the voltage applied. The motors I used were specified to consume only 14 milliamps. Therefore, I needed only to assume that the relay contacts I chose could handle this amount. As a general rule of thumb you should pick a contact rating that is twice the amount needed. With that out of the way, let's jump into electronic control.

Electronic Switches. Relays tend to be noisy, both audibly and electrically. They can also consume as much power as the motor we are trying to control. Not very efficient. Electronic controls don't have these problems. Let's reproduce the circuit of figure 5a using electronic switches. The switches used in figure 5c are transistors, and they act like mechanical switches when their control voltage is present. The same rules apply to this circuit as the previous ones. Activating both transistors on one side will short out the power supply. It takes a little more understanding to realize the action of these devices, and it is beyond the scope of this article, but several excellent books are listed at the conclusion.

Suffice it to say that a ground potential on A or D will activate them, and a positive voltage on B or C will allow them to operate. In order for these devices to feel their potential, a method of developing the levels is necessary. Resistors must be added in series with the control pins. This control pin is called the base. Figure 5d depicts a com-

plete forward-reverse circuit for the motor used in the hand.

The circuit shows that electronics can reduce the control problem to the point where we need only one signal to provide forward or reverse. A general enable switch transistor can be added in the same manner as shown in the first figure. Transistors that must switch power to a load should be PNP types or those with the arrow pointing in. Transistors used for providing ground return paths are NPN with the arrow pointing out. Therefore, enabling the circuit by switching ground would require an NPN-type transistor with a corresponding positive level on the base for activation.

Feedback. We now have the capability of turning the wrist left or right, opening and closing the hand, raising and lowering the wrist, and extending the arm. What more could we want?

How about knowing where the arm is? What position is the hand in? This type of information must be fed back into our master control if the robot is to be capable of reaching for and obtaining an object. We, as humans, use a multitude of sensors for feedback, the main one being vision. Electronic vision systems are extremely complex and the subject of an entire article. (*See Andrew Filo's article on page 36 in this issue for a consideration of one approach....Ed.*) There are simpler methods. Enter the limit switch.

Limit switches do what they say: they detect the moving object reaching its physical limit. You might envision them being placed on the finger tips to detect the presence of an object, or on the top of the forearm to signal when the wrist is pitched up as far as it can go. These switches are nothing more than small replicas of those used in figure 5a. Commonly called microswitches, they usually come with some sort of lever mechanism over the plunger to activate them. Figure 6 illustrates various positions for limit switches in the arm described here.

Limit switches are only a method for ensuring that we don't keep trying to move when we physically can't. If we want to detect exactly where the arm or hand is at any given moment, some sort

of position sensor is necessary. Detecting the location of an arm or hand can be done in many ways.

Opto Electronics. Here is where light and electronics merge. We can sense the presence or absence of light with phototransistors, which are just like the switches used for control in figure 5 but the base control voltage is replaced by the presence of light through a tiny lens built into the case. We can detect location by drilling small holes in the circular wrist base (shown in photos). Position a light source such as a small light bulb or LED (light-emitting diode) so that it is shining down through the holes. Underneath, mount a phototransistor so that the light strikes the lens. This completes the path activating the transistor. Now turn the wrist. As each hole moves away from the beam of light, it opens the circuit that deactivates the transistor. This will provide a series of pulses on-off-on from the transistor which could be counted by your master control to determine position. Figure 7 is provided to fire your imagination in the use of opto electronics for position feedback.

Magnetic. Although opto electronics seems to be the neatest way to accomplish position feedback, there is another method, called *Hall-effect switching*, that is a personal favorite. It involves the presence of a magnetic field, and the devices used detect this presence and switch accordingly.

The Hall-effect phenomenon was first discovered in 1879 by E. H. Hall when he noted that a magnetic field, placed near a conductor that was carrying current, produced a voltage across the conductor. Today there are several manufacturers that make Hall-effect integrated circuits, and they are very inexpensive (often cheaper than mechanical switches). In light of this fact, I use them as both position and limit sensors.

All electronic, the Hall-effect switch adapts easily into robot control circuits (see figure 8). Opto electronic switches do everything that magnetic sensors do, yet they don't require precise alignment between field and sensor as is the case with the light beam. A small magnet, or series of them, placed around the disk

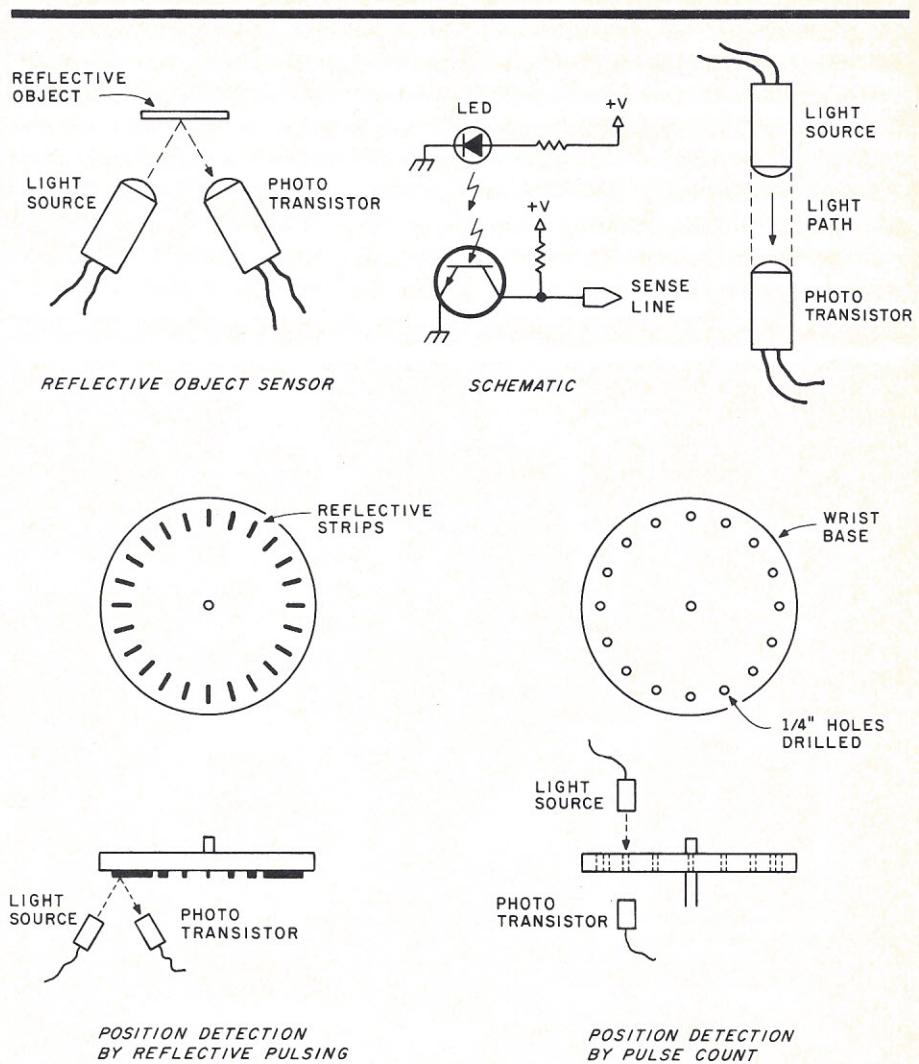


Figure 7: Basic opto electronic sensing methods and applications.



Photo 5: From reading machine to robot arm mechanism. Shown is the lead screw assembly used in the arm.

of the wrist base, will activate the sensors beneath without the need for another electronic device above. Various ideas for implementation are illustrated in figure 8.

All of the aforementioned sensing methods have one disadvantage however — they can only report position as close as the next physical activation point allows. For instance, the limit

switch only senses the end of travel, the opto sensor relays positional increments as small as the number of holes physically allows, and the Hall-effect system, similarly, as close as the next magnet. What if we want constant reporting?

Servo to the rescue!

Servo is the name applied to a method of positioning a motor exactly

where you want it and holding it there, using a potentiometer or variable resistor. The varying voltage coming out of the potentiometer is applied to a circuit that measures the amount and compares it to a predefined level (the position you want). During the time the two voltages don't equal each other, the circuit runs the motor. The shaft, or wiper arm, of the potentiometer is connected physically to the mechanical rotation of the object controlled, such as the wrist. The circuit will allow the motor to move, seeking out this equality of levels. When the two voltage amounts are equal, the circuit disables the motor and you are at the position desired.

You can build a simple servo circuit like the one shown in figure 9, or you can purchase any of a multitude of available servo master control integrated circuits (see information at the end of the article).

At this point, we know how to control the motors forward and reverse, off and on, and to sense their position. Now what, you ask? Remember I mentioned a certain "master control" throughout the article?

Meet the Micro. Micro's his name, master control is his game. Hold onto your hats because you are about to enter the world of computer control.

A computer consists mainly of three units: the control program, which tells the instruction processor what to do next; the instruction processor, which receives these commands and does what it's told; and the input and output section that the instruction processor uses to get further information or to give results to other devices. Other names for these sections are ROM, CPU, and I/O. ROM comes from read-only memory. Although control programs can be stored or remembered in programmable memory, they generally use read-only memory. The CPU is the instruction processor, or central processing unit. I/O is the acronym for input/output. In a computer such as the one used for robot control, I/O would be limit switches and position sensor inputs and motor control outputs.

Going a little deeper, let's take a look at a typical instruction that informs the

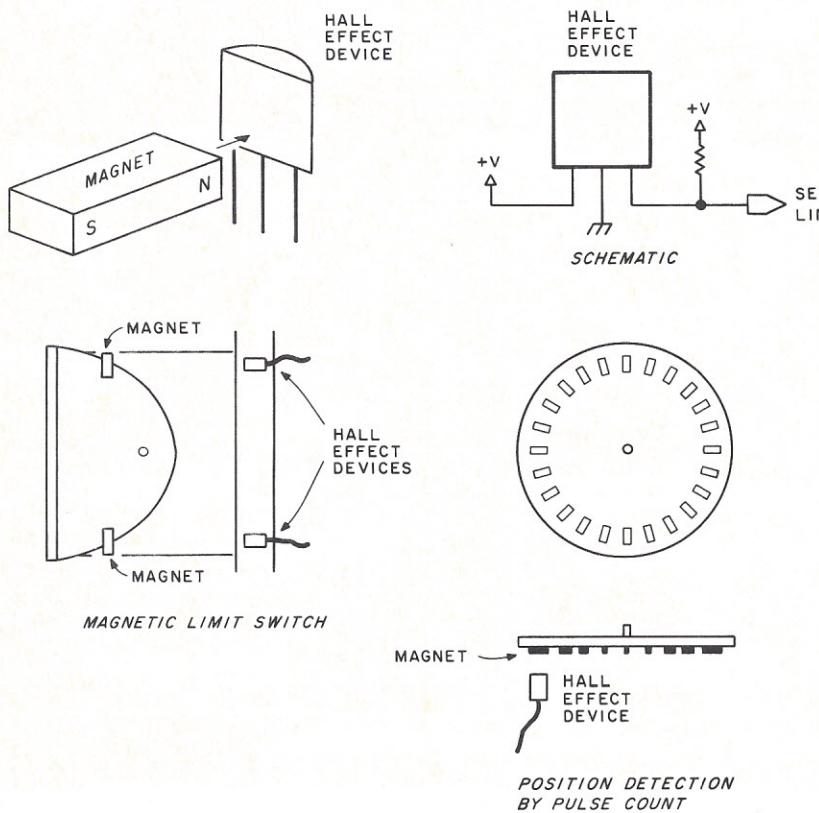


Figure 8: Basic magnetic detection methods with various applications.

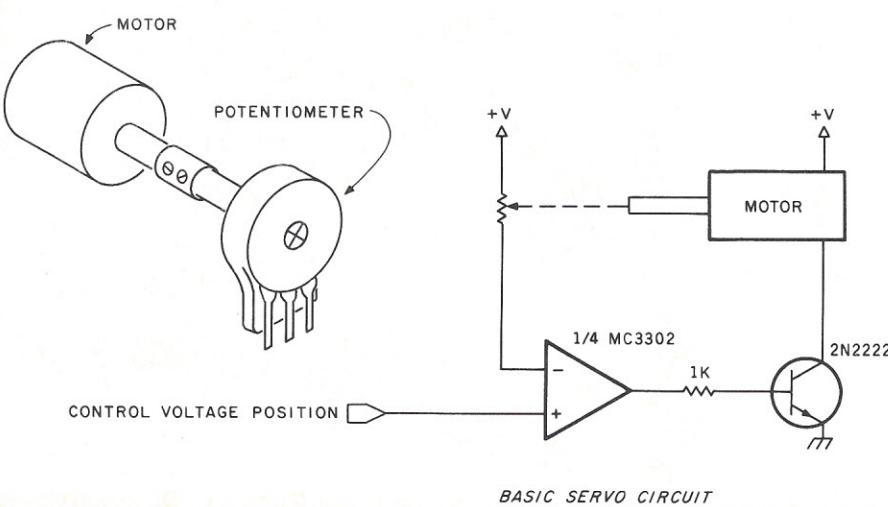


Figure 9: Simple servo description and circuit.

processor to change the direction of a motor (see figure 10). First, the instruction "change direction" is fetched from memory by the processor. When the instruction code arrives, the processor determines that it is an output instruction, then it commands the output circuits to change direction by changing the voltage level on one output pin. Note that this control line could be used with the motor control circuit shown in figure 5d.

The next action the processor takes is to fetch the next instruction from memory. This fetch-decode-execute cycle goes on and on in a computer. Basically, it's like following the instructions on a shampoo bottle: lather, rinse, repeat. These recipes or groups of commands used to accomplish a task are called algorithms.

In a motor control system you could instruct the computer to move the wrist until six pulses were counted from an

CONTROL PROGRAM

| | |
|---|------------------|
| 5 | |
| 4 | STOP MOTOR |
| 3 | SENSE LIMIT |
| 2 | ENABLE MOTOR |
| 1 | CHANGE DIRECTION |

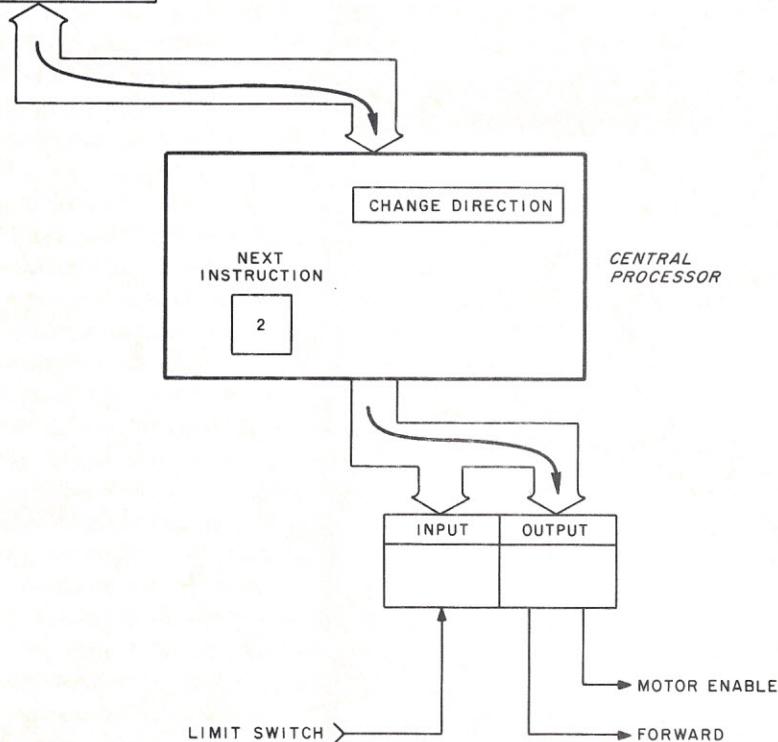


Figure 10: Illustration of the flow within computer system of control instruction to CPU and from there to output.

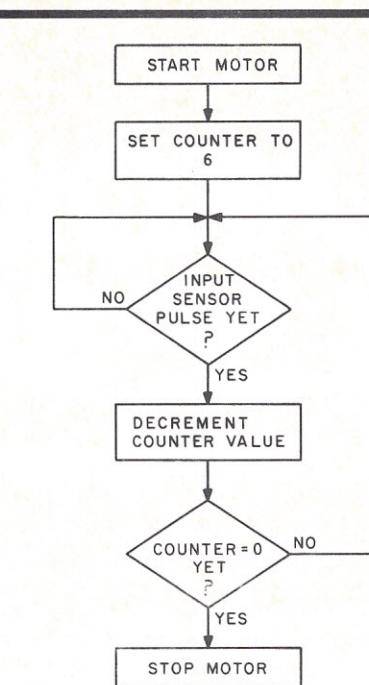


Figure 11: Basic program flow chart detailing the steps necessary to count six pulses and stop motor.

opto electronic sensor. The algorithm used to accomplish this is illustrated in figure 11. By the way, the blocks and structure used in this figure are called a flow diagram or flowchart, and they are used universally in all computer programming. Just as the motors and switches are referred to as robot hardware, the control program of the master computer is called robot software.

With this I'll let you go for another issue. Experiment with the techniques used and if you aren't yet familiar with computers, refer to some of the books I've listed. Next time we'll see how all this goes together as we construct an intelligent programmable motion platform that we can use to explore varying methods of robot path navigation. □

REFERENCES

Computer Books:

Basic Microprocessors and the 6800
Ron Bishop
Hayden Books

Handbook of Microprocessor Applications
John Kuecken
TAB Books

Master Control Books:

Solid State Motor Controls
John Kuecken
TAB Books

Introduction to Servo Mechanism System Design
W. Humphrey
Prentice-Hall Books

Basic Electronics Books:

Understanding Solid State Electronics
Texas Instruments Learning Center
Radio Shack Books, #62-2035

Transistor Circuit Design
Texas Instruments
McGraw-Hill Books

Motor IC Suppliers:

Sprague Electric
70 Pembroke Rd.
Concord, NH 03301
Devices: stepper drivers, Hall-effect IC's, motor drivers.

Signetics
811 East Arques Ave.
Sunnyvale, CA 94016
Devices: motor drivers, servo systems, speed controls.

Texas Instruments
POB 225012
Dallas, TX 75265
Devices: motor drivers, Hall-effect, sensors.

THE POLAROID P100 POLAPULSE BATTERY

Solution Waiting for a Problem

Martin Bradley Weinstein

Over 300 million packs of SX-70-style film ago, Polaroid Corporation developed a unique planar battery technology that resulted in an extremely thin, flat, lightweight battery with extraordinary electrochemical characteristics. Among these are an extremely low battery source impedance (on the order of 0.05 ohms), an excellent shelf life (three years and more), low drain rate efficiencies comparable to those of alkaline cells (230 mAh at 20 mA) but with much better peak current capabilities (26 Amps instantaneously), and 6 V in each thin package.

Now Polaroid has taken this

technology and repackaged it in a slightly smaller envelope (3.730 by 3.040 by 0.180 inches, or 94.74 by 77.22 by 4.57 mm) for over-the-counter commercial availability in the near future. In the meantime, this 0.95-ounce workhorse has been incorporated into the #4155 Polaroid Polapulse 6 V Battery Designer's Kit, which includes five P100 batteries, a molded battery holder, and a technical leaflet.

The size and power characteristics of this battery suggest a large number of possible applications in robotics and related fields. First, let's take a look at the construction and specifications of the P100.

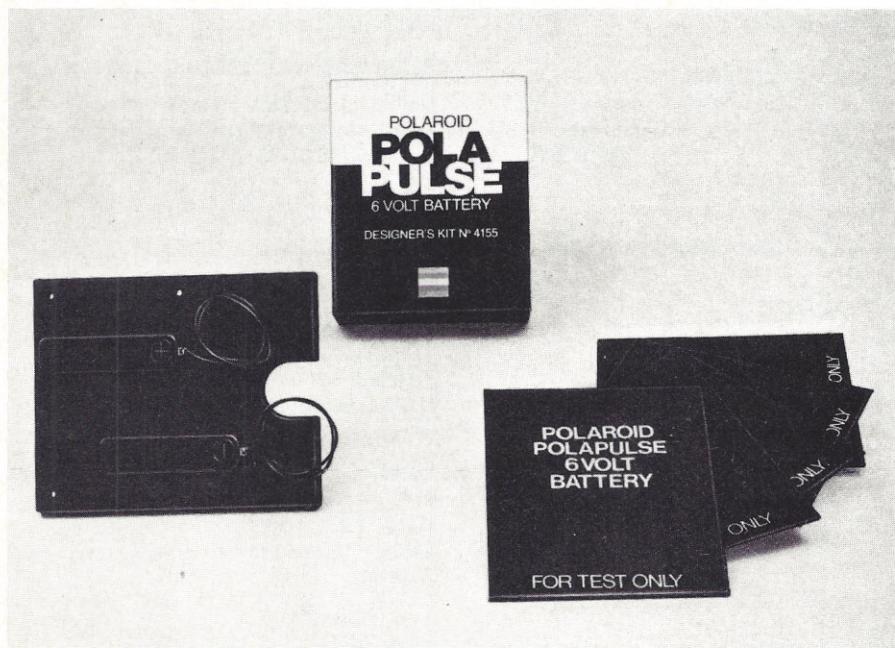
Electrical Characteristics. The P100 battery is a planar power source that offers a nominal 6 V at its terminals. Actual open circuit voltage is 6.8 VDC maximum, and Polaroid defines its useful life as continuing down to 3 VDC terminal voltage; this, of course, may vary with your application.

The maximum high rate discharge, which is specified as driving a 0.05 ohm load, offers an instantaneous 26 Amps, which reduces to 5 Amps after 30 seconds, 2½ Amps after 60 seconds. The internal resistance of the battery at a nominal 1 Amp load is on the order of 0.25 ohm.

When tested against AA cells (in groups of four) at loads to 4 Amperes for 150 milliseconds with 15 second "rest" periods, the P100 outperformed zinc chloride cells, carbon-zinc cells, and alkaline cells, maintaining both a higher terminal voltage and a higher output current capability.

Temperature tests showed approximately 63 percent of rated capacity available at 20°F, 80 percent at 40°F, 92 percent at 60°F, 100 percent at 80°F, and 104 to 106 percent at temperatures from 100 to 140°F.

Since we can anticipate that the nominal 6 V terminal voltage suggests a number of microprocessor applications (including auspicious use in memory protection), we paid special attention to its moderate-drain characteristics down to 5.0 and 4.5 VDC. At 100 mA drain, the P100 discharges to 5.0 VDC after one hour, to 4.5 VDC after 80 minutes of con-



Photos courtesy of Polaroid Corporation.

Photo 1: The Polaroid Polapulse designer's kit comes equipped with 5 batteries and a battery holder designed specifically for the Polapulse.

tinuous use. At 50 mA continuous drain, it reaches 5.0 VDC after 2 hours and 45 minutes, 4.5 VDC after 3 hours and 10 minutes. Polaroid's own specifications down to a terminal voltage of 3 VDC are included in table 1.

The physical orientation of the terminals is also noteworthy. Both appear on the same side of the battery and are set back from the edge of the battery at different distances. This configuration, in concert with the design of the molded battery holder, renders accidental polarity reversal on insertion virtually impossible.

The battery occupies a volume of 1.85 cubic inches (30.2 cc) and tips the scales at a hefty 0.95 ounces (27 grams).

How It Works. Since the Polapulse battery uses fairly standard Leclanche chemistry (commonly referred to as carbon-zinc), its unique characteristics are almost entirely due to its planar construction. The actual reactive species are zinc and manganese dioxide.

The materials used (see figure 1) are flat sheets of aluminum laminated with conductive plastic sheets, a non-woven synthetic fiber separator sheet, gelled electrolyte, and appropriate adhesives — plus an overwrap outer package of paper and polyester. The cathode is an aluminum electrode with laminated conductive plastic sheet coated with manganese dioxide; the anode is a similar arrangement coated with zinc. The internal electrodes are a *duplex* arrangement, with a conductive sheet coated with zinc on one side, manganese dioxide on the other. The intervening separator sheets are sealed into the assembly by an adhesive coating about their perimeters, thus containing the gelled electrolyte completely.

The vent is a membrane design that passes only gasses, trapping any liquids inside. The outside structure of the battery is not consumed by the electrochemical reaction because it simply isn't a component of that reaction. According to Polaroid, this effective sealing mechanism has resulted in no known case of leakage damage, a record that includes 300 million Polapulse batteries incorporated into SX-70 film packages. (Note: Though

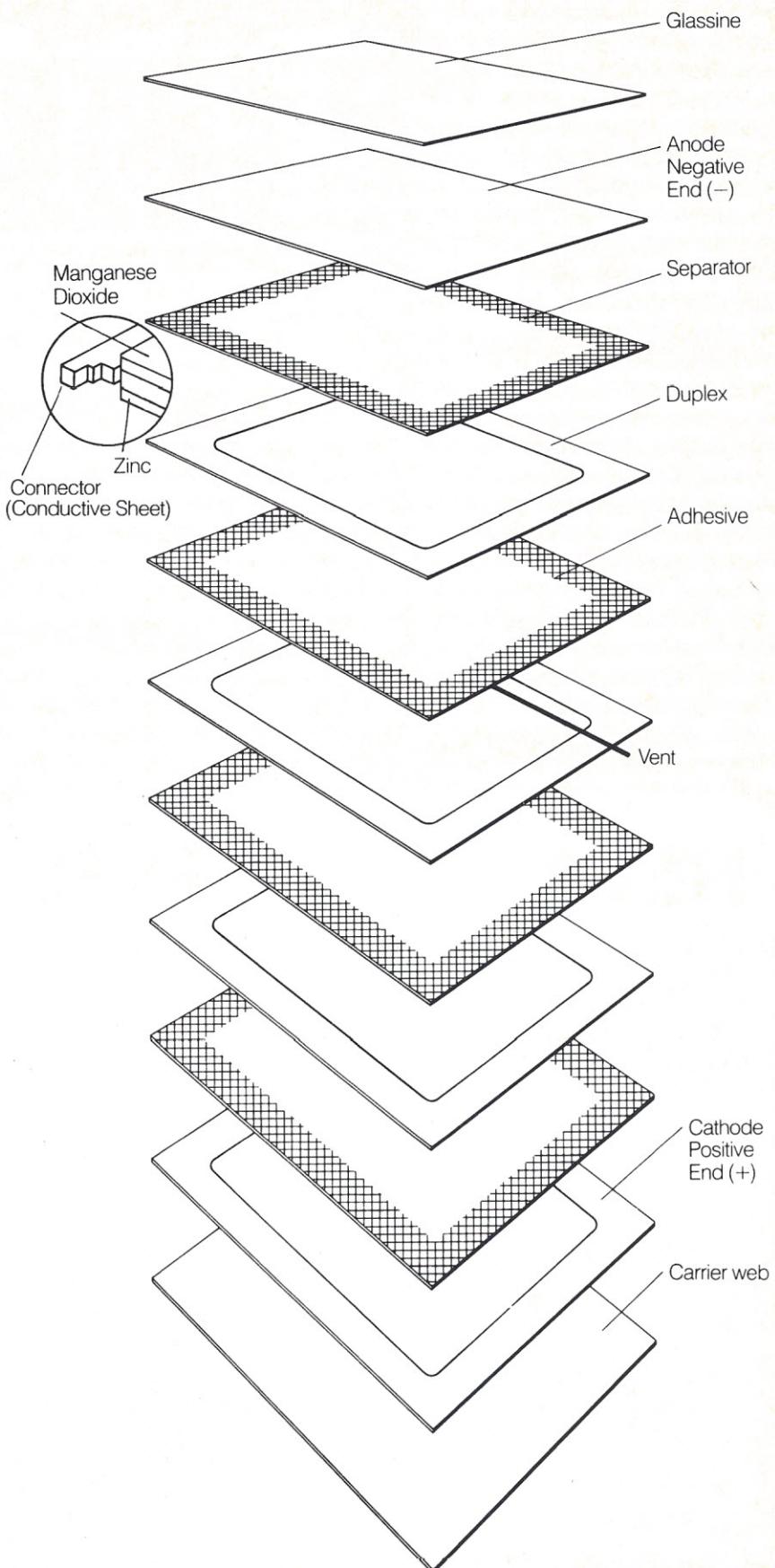


Figure 1: The Polapulse P100 battery consists of alternating layers of aluminum, synthetic fiber, and electrolyte. The package is sealed in a paper and polyester wrapping.

electrochemically identical to the P100, the film pack batteries reflect minor differences in overall physical package design and terminal positioning.)

Polaroid has followed guidelines and test protocols as defined in suggested Federal Hazardous Substances Act regulations, and found "The battery performed extremely well even under severe conditions... the battery did not explode with various attempts to recharge it, or even when it was exposed to fire."

The large surface area provided by this planar construction technique is the reason these batteries are capable of providing such outstanding peak discharge performance, low internal resistance, and high power-to-weight and power-to-volume ratios. The sealed construction means exceptional safety and long shelf life. And 300 million packs of film, we think, are an excellent reason for Polaroid to have poured its research and design money into developing such a remarkable little power source.

Now let's see what it can do for us.

| Current | Hours | Minutes | Seconds | milliAmp-Hours |
|---------|-------|---------|---------|----------------|
| 20mA | 11 | 30 | — | 230 |
| 50mA | 3 | 54 | — | 195 |
| 100mA | 1 | 42 | — | 170 |
| 500mA | — | 14 | 42 | 123 |
| 1 Amp | — | 5 | 42 | 95 |
| 5 Amps | — | — | 24 | 33 |

Table 1: Discharge characteristics chart developed after testing at Polaroid laboratories. The times show how long the battery remains above minimum rated voltage at the specified current draw. Typical of all batteries, a slower discharge rate produces more useful energy. The low discharge values shown are compatible with many applications using CMOS control circuitry.

Applications. As we mentioned, this Polapulse battery seems an excellent choice for on-board memory protection backup power. At least one manufacturer, we understand, is incorporating it into a product for the STD bus, although specifics were unavailable at this writing.

Indeed, low power consumption by any system — the plethora of new CMOS microprocessors comes to mind — suggests immediate compatibility with the capabilities of the P100 as a

primary power source.

The P100's excellent shelf life and high peak current capabilities suggest it for a number of safety and alarm subsystems, such as the safety light curtains federally mandated to surround any number of machine tools and certain industrial robot installations.

Home enthusiasts working on miniature mobile robot platforms may want to take advantage of the battery's physical compactness for any number of uses, including motor drive of small motors, wireless radio, or infrared remote controls. The same characteristics suggest this battery for use in artificial limb prosthesis and related medical applications. And there are a number of portable devices, from calculators to timekeepers to test instruments, which all seem well suited to the P100's capabilities.

Experimentation is more than invited here, it's urged.

Availability. The Polaroid Polapulse Designer's Kit #4155 includes five P100 batteries, a molded battery holder, and a technical leaflet. It's currently available from Polaroid for \$16.75 (plus applicable taxes). The battery holder alone, which features contacts made to Polaroid's recommended design and red/black color coded leads, is available for \$1.55 (plus taxes). Either can be ordered by sending a check or money order to:

Polaroid Corporation
Commercial Battery Division
784 Memorial Dr.
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Please write us to share your successes with the P100. □

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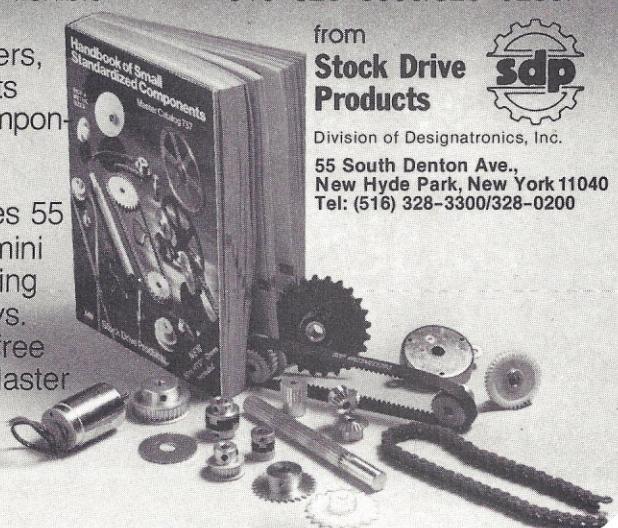
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NEW ROBOT BOOKS FOR THE BOOKCASE

David Smith

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Several new books have caught my eye since my list of robot books was published in the September/October issue of *Robotics Age*. To keep the list up to date, here are the latest discoveries.

The Unicorn-1 articles in *Radio-Electronics* have been reprinted. You can now get the complete series by writing to:

Radio-Electronics
Robot Reprints
200 Park Ave. South
New York, NY 10003
\$12 plus \$1 shipping

Software Engineering for Micros
T. G. Lewis
Hayden Book Company Inc.
Rochelle Park, NJ 07662
1979, \$6.95

An interesting approach to error-free, transportable software that results in a number of small modules.

How to Design and Build Your Own Custom Robot
David L. Heiserman
Tab Book 1341
Tab Books Inc.
Blue Ridge Summit, PA 17214
1981, \$12.95

The latest of several robot books written by Heiserman. The book is thick, well written, and includes circuit diagrams and software listings for the Z80 or 8080A/8085 microprocessors.

Software Tools
Kernighan Plauger
Addison-Wesley Publishing Company
Reading, MA 01867
1976, \$19

Shows how to build software tools using structured programming. Written using Ratfor (Rational FORTRAN)

but could be translated into other languages.

DC Motors, Speed Controls, Servo Systems

An engineering handbook from Electro-Craft Corporation
1600 Second St. South
Hopkins, MN 55343
(612) 931-2700
1972, \$3

A very good book and a catalog of very good motors. It should answer most of your technical questions on DC motors, speed controls, servo systems, and optical encoders. I'm glad I ran into this one!

68000 Microprocessor Handbook

Gerry Kane
Osborne/McGraw-Hill
630 Bancroft Way
Berkeley, CA 94710
1981, \$6.95

The 68000 is one of the newest and most powerful 16-bit microprocessor chips. With built-in logic to handle bus arbitration in multi-processor setups, direct addressing of 16 megabytes, 8 MHz speed, and 16-bit power, it will probably be used in many robots.

An Introduction to Microprocessors: Experiments in Digital Technology

Noel T. Smith
Hayden Book Company
50 Essex St.
Rochelle Park, NJ 07662
1981, \$10.95

Covers far more than just microprocessors. Begins with a discussion of the "abstract" side of digital electronics but then rolls up its sleeves and leads you into the real world of building and programming hardware. It would make a good text book.

The remainder of this list covers information sources. Most of the items do not have a direct bearing on robotics, so someone will have to do a little legwork.

National Technical Information Service (NTIS)
US Department of Commerce
5285 Port Royal Rd.
Springfield, VA 22161

Ask for the *NTIS Information Services General Catalog*, which is free, and the *Tech Notes Information*, also free. NTIS also does computer database searches for a fee, but you can get a free copy of *Current Published Searches*, which covers the computer database searches done by others and tells you how to order one of your own.

More information comes from *A Consumer's Guide to Federal Periodicals*, which is free and can be obtained from:

Superintendent of Documents
US Government Printing Office
Washington, DC 20402

A branch of the US Federal Government, called the Federal Information Center, will help you through the maze of government offices. You can get the address of the local office from:

General Services Administration
Washington, DC 20405

If all of this is too much to wade through, try:

Finding Facts Fast
Allen Todd
Ten Speed Press
900 Modoc St.
Berkeley, CA 94707
1979, \$3.95

Continued on page 35

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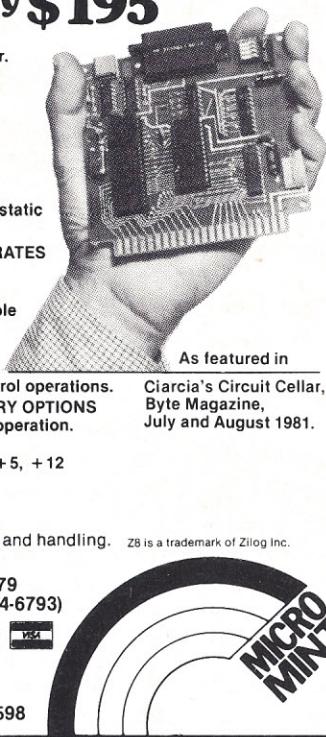
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- 8 Micro Mint, p. 34
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Book Review

Continued from page 13

manufacturing and will move to the construction industry, and concludes with a look at the use of robots in the home and in space exploration.

The discussion of the implications of widespread robot use in the following chapter will fuel hours of debate. Albus proposes unions that encourage the use of robots, a National Mutual Fund, financed with credit from the Federal Reserve System, that will bring about higher productivity in industry through robots, and mandatory savings bonds to counter inflation.

Finally, six pages of suggested material for further reading are included, along with an index.

Brains, Behavior, & Robotics is pleasant to read, but certainly doesn't fit into the category of light reading. The descriptions of the hierarchical control system and the Cerebellar Model Arithmetic Computer are enough justification to buy the volume, and the studies of our nervous system and the future of robotics are the gravy poured on top. I'm glad to have it on my shelf. □

ROBOT BOOKS

Continued from page 33

Most of the work done in universities is available to the general public. Try writing to their engineering departments or computer centers.

University of Rhode Island
College of Engineering
Robot Research Group
Kingston, RI 02881

Stanford Department of
Computer Science
Publications Office
Stanford University
Stanford, CA 94305

Massachusetts Institute of Technology
Laboratory for Computer Science
545 Technology Square
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If you know of any other books, please let me know. □

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NOV/DEC 1981: Teach Your Robot to Speak; Fast Trig Functions for Robot control; An Interview with George Devol; The Great Japanese Robot Show; TIMEL: A Homebuilt Robot, Part II.

JAN/FEB 1982: Avatar: A Homebuilt Robot; A Look At SS-50 Computer Boards; Working Within Limits; Ambulatron: Another Contest Winner; Quester.

MAR/APR 1982: The Rhino XR-1: A Hands-On Introduction to Robotics; Power for Robots; A Computer Controlled Sentry Robot: A Homebuilt Project Report; Natural Language Understanding: A First Look; RT-13 Video/Sound Recognition System; An Inexpensive Hand; Type 'N Talk.

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APPLYING ROBOT VISION TO THE REAL WORLD

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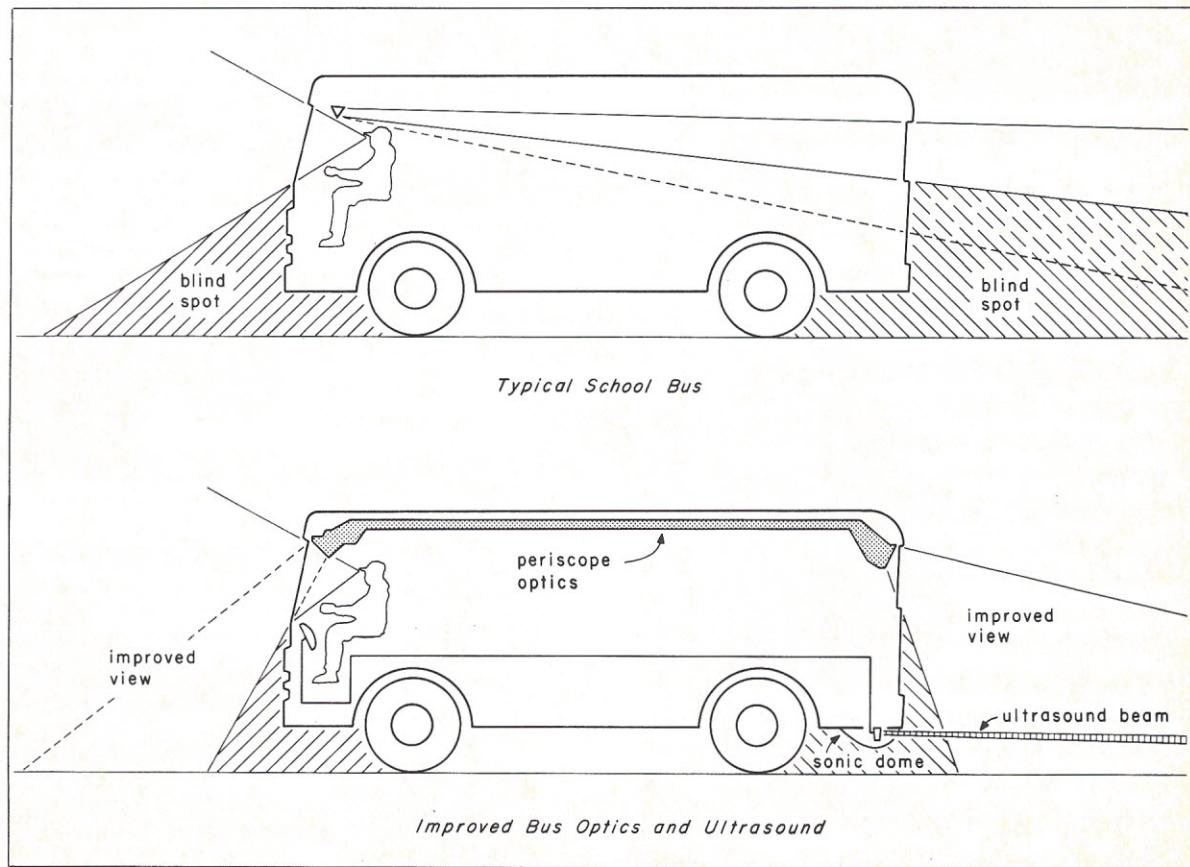
Since the advent of practical solid-state imaging devices, single-chip computers, and good image analysis software, industrial robot vision has advanced immensely. Overnight, there has been a change from simple photoelectric devices that could only detect the presence or absence of an object to imaging systems that can accurately recognize, measure, and inspect a product. And with these recent advances, it appears there will be an emergence of a new generation of consumer products using *artificial vision*.

Artificial vision, unlike current home video equipment, will supplant natural vision. The

technique employs a process whereby optical images are sensed, defined, analyzed, and recognized. Due to new computer and solid-state technologies, artificial vision is a small-sized, low-cost, powerful aid to all people with visual handicaps.

School Bus Blind Spots. The first application of artificial vision I was involved in concerned school buses. Every day millions of school age children ride buses that are designed primarily to move a volume of children safely and dependably while maintaining a long service life. In

Figure 1: The most severe blind spots in a school bus are located in the front and rear. Although the driver is seated high, it is difficult to see over the steering wheel and dashboard. Benches where children are seated or standing present further obstacles to the driver's visibility. To date, several types of experimental improvements have been tried by various organizations, including a periscope rear-view system with an additional front-view mirror and an ultrasonic scanning dome. The periscope system is expensive and elaborate, while the ultrasonic system tends to be ineffective in detecting a child dressed in heavy winter clothing.



order to achieve this goal economically, however, some of the driver's vision is sacrificed, notably in the immediate front and rear of the bus. Structural members, seats, and doors all create obstructions, leaving the driver hampered by blind spots, and resulting in the deaths of many children as they leave the bus and move out of the driver's range of vision.

To help solve this problem, I recently participated in a research effort to develop a system that could see and report intrusions into the front and rear blind spots. A requirement for the system was that it begin monitoring the blind spots as soon as the bus stopped. Additionally, the system was to continually test itself. If it failed, it would signal the operator. The last requirement was that the system not only alert the

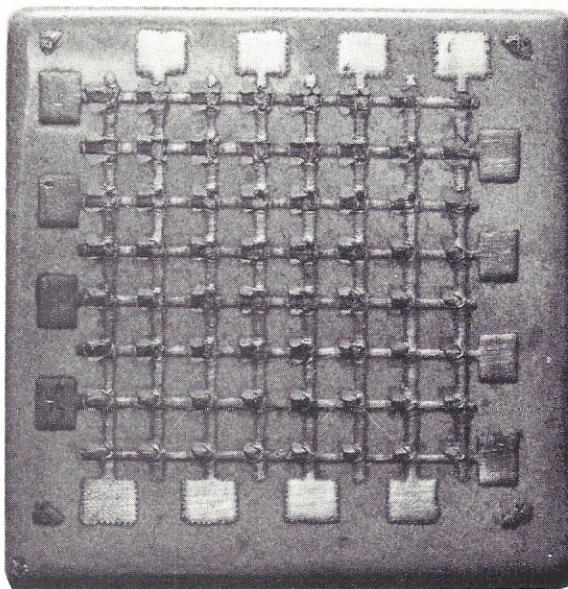


Photo 1: A close-up of the array used in the artificial vision device.

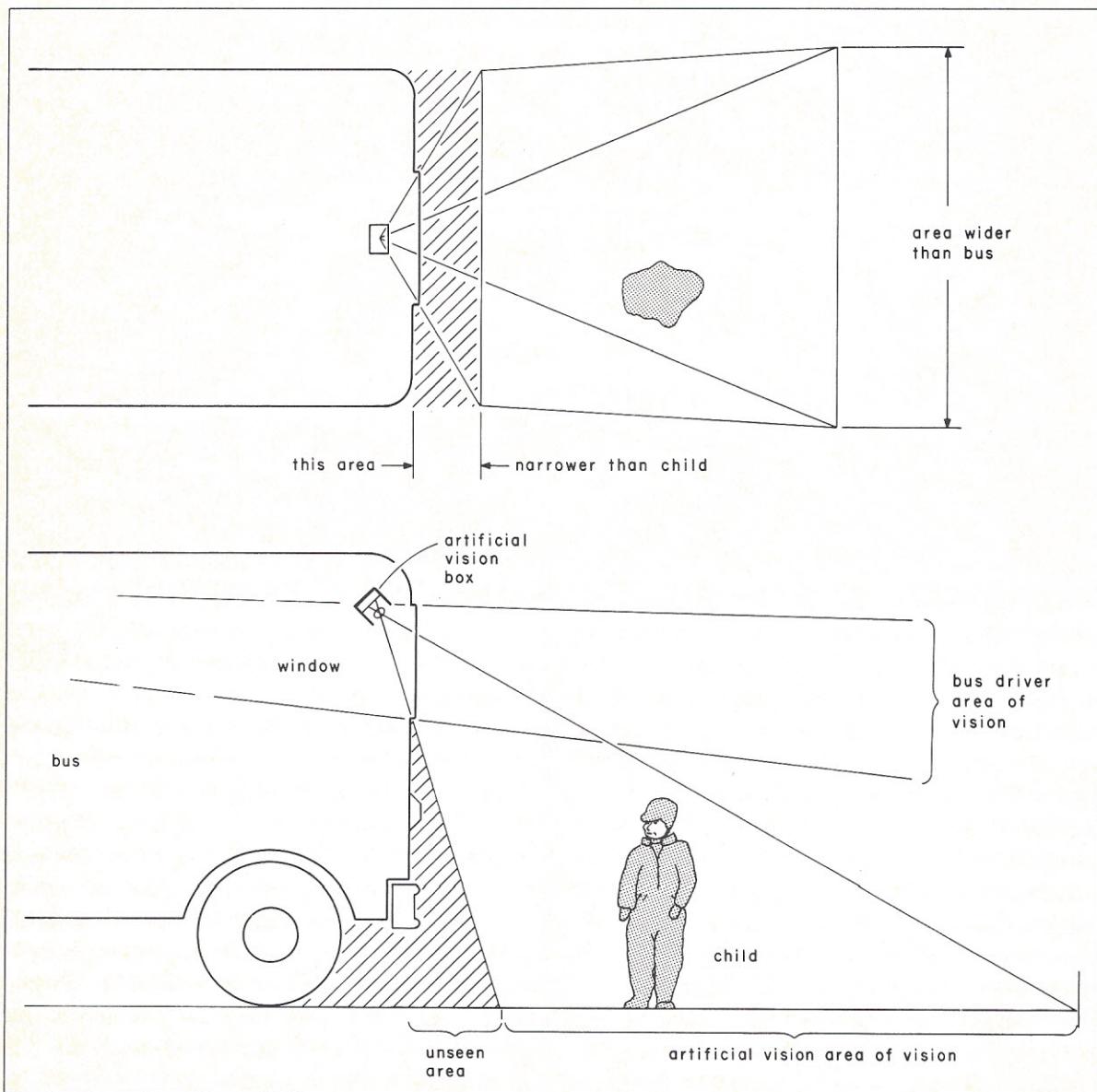
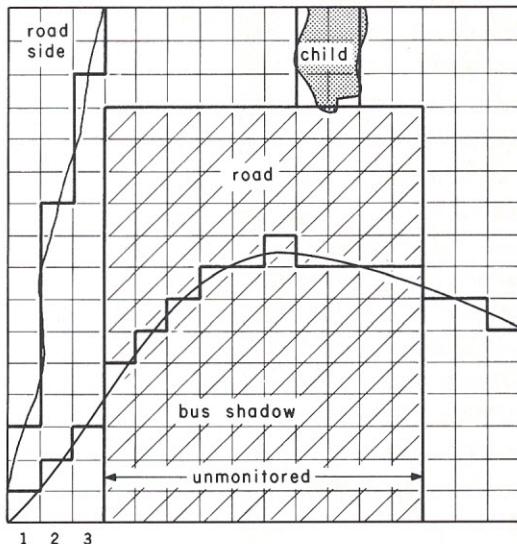
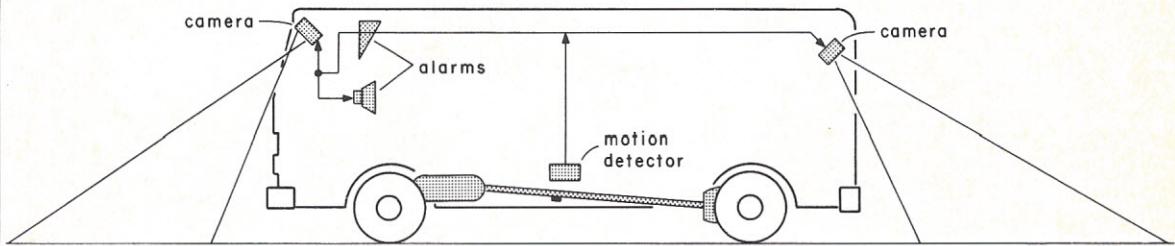


Figure 2: The artificial vision box is mounted inside the bus and looks out through an existing window. The box located at the rear of the bus is designed to monitor the perimeter of an area wider than the bus, since the bus might turn while backing up. The area covered is about fifteen by twenty-five feet, large enough that the driver, when warned, has sufficient time to stop.

Figure 3: An installation of the bus back-up alarm consists of two artificial vision boxes, an audiovisual alarm, and a motion detector that monitors the drive shaft. When the bus stops, the motion detector signals the artificial vision system to begin operation. The system scans a 3-pixel-wide band around the edge of a scene. The scan information is stored in the computer and used as a reference against which further scans are compared.



Vision Array Geometry



Bus Installation

driver if something was moving in the blind spots, but reinforce the driver's habit of checking the blind spots. By design, the system had to be reliable, easy to install on existing buses, simple to maintain, and low cost.

Figure 1 shows a diagram of the typical school bus and its blind spots. One possible solution, improved front and rear view optics, was ruled out due to high cost and installation problems. Another solution, the use of ultrasonic monitoring, involved reflecting an ultrasound beam off a child who was behind the bus. While promising, this system was ineffective in detecting children wearing soft, sound-absorbing clothing. Maintaining the externally mounted transducer dome was also found to be a prob-

lem, since road grime or ice deposits rapidly reduced the effectiveness of the system.

These facts led to the reasoning that the best way to monitor the blind spots would be to use an artificial vision system that looked through the existing bus windows. Figure 2 shows the placement of such a system. The strategy is fairly simple: the system would look at an area large enough to overlap the driver's visible regions behind and in front of the bus, and alert the driver when small changes in the surveyed area occurred. A mirror-mounted alarm would sound briefly every time the bus stopped, to remind the driver that blind spots exist.

The artificial vision system developed for field testing consisted of a custom-built thick film ar-

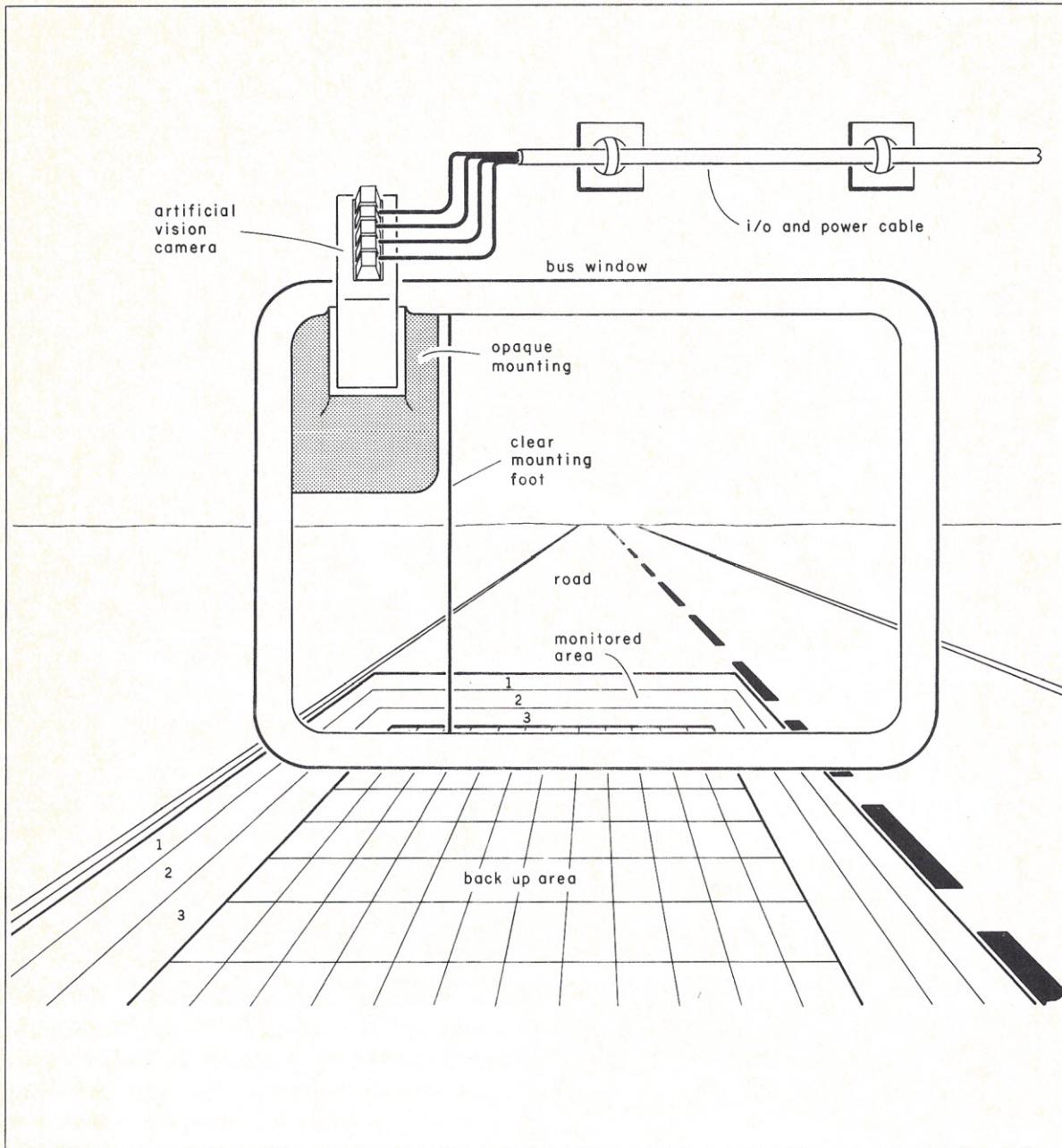


Figure 4: A driver's view of the coverage provided by the artificial vision box. Notice that most of the monitored area is not visible to the driver. Furthermore, the box is mounted to the window with a clear mounting foot that is slipped under the rear window gasket, so the box is unobtrusive to the driver's rear view. There is also an opaque mounting which serves as a shield, blocking stray illumination from the interior of the bus.

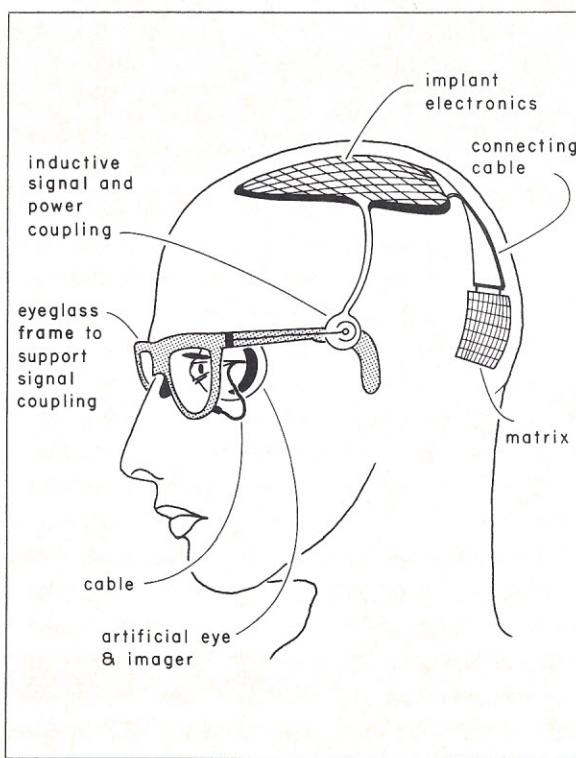
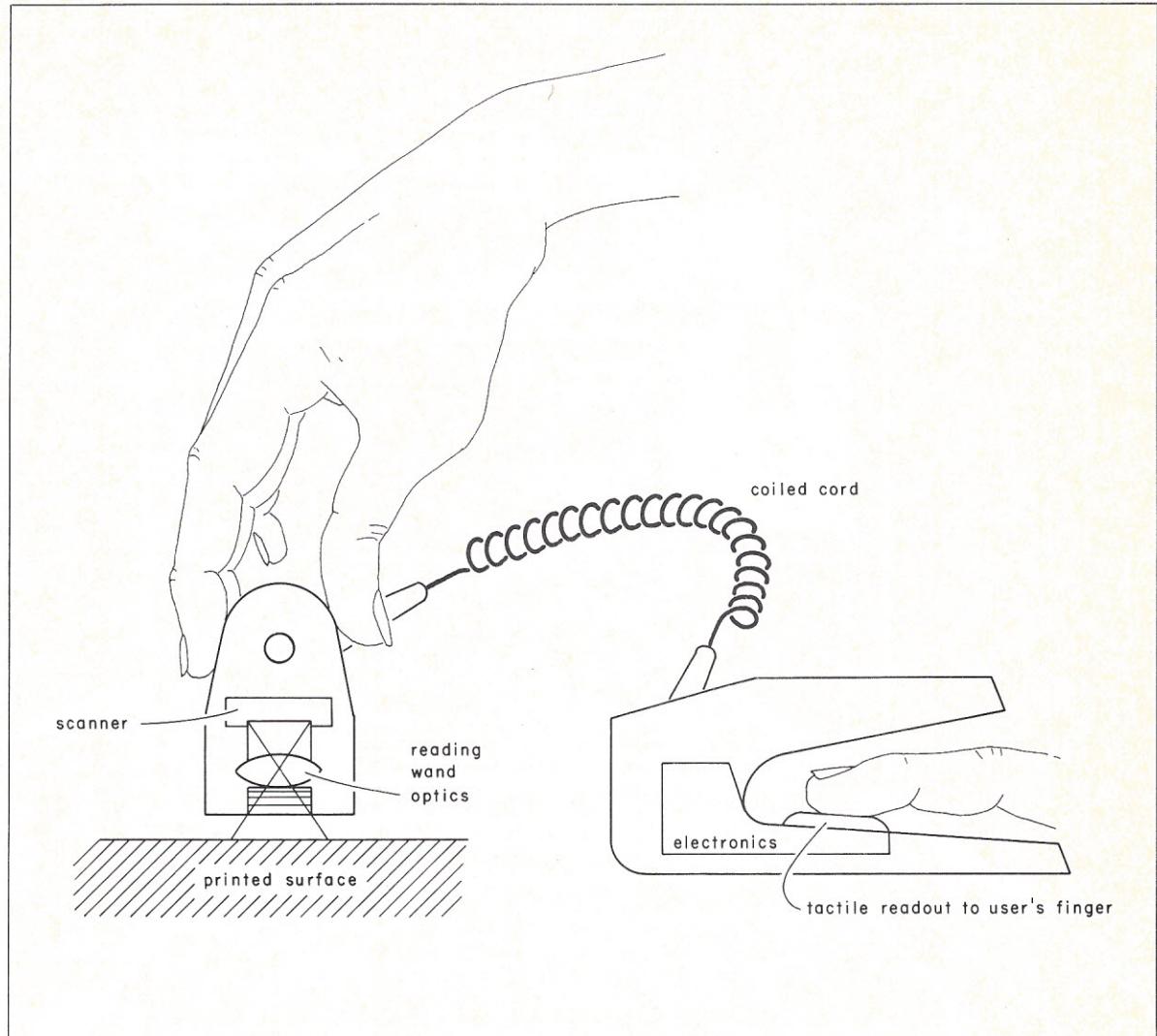
ray as shown in photo 1. This array of 64 one-bit addressable pixels (picture elements) was controlled by a small 4-bit microcomputer chip. Figure 3 shows how the system works. When the bus halts, the drive shaft stops turning. A motion detector senses the drive shaft has stopped and alerts the computer. At this point, the computer runs a self-test program. The self-test program reads the array to check for single bit pixels stuck in an on or off state, and briefly activates the alarms. If the self test is successful, the array is repeatedly scanned and the state of each pixel is compared against the pixel's state recorded during the self test. If the pixel changes in value it is flagged but the alarm is not sounded. However, if an adjacent pixel on the inner

row changes, the alarm is sounded. To prevent false alarms the computer is programmed to ignore intrusions wider than three columns or rows in the sensor array since these are usually caused by such things as a passing car's shadow.

Adequately alerting the driver is an important feature of the system, accomplished by an audiovisual unit attached to the rear view mirror. When the bus first stops, the system performs a self check that concludes by briefly activating the alarm. This brief activation not only signals that the system is functional, but reminds the bus driver to check the front and rear of the bus before starting up.

Tests conducted on this system showed that window mounting of the system was simple and

Figure 5: Two popular schemes to give sight to the blind involve electronic conversion of an optical scene into either a tactile or neurological representation. The simpler scheme (figure 5a) uses a hand-held wand that manually scans documents or flat objects. The second scheme (figure 5b) is much bolder, and proposes that one or both of the blind person's eyes be removed and replaced with a glass eye containing a small solid state camera.



cost effective. Figure 4 shows how the camera box is mounted on the windows. Since the box is mounted inside, it is removed from the harsh road environment, and with the optics focused on the road, debris on the window does not have a drastic effect on the road image. Routine bus washings insure that the windows are clean enough for system operation.

Photograph 2 shows a prototype system. The prototype system has undergone testing in an automotive environment and has proved acceptable in its processing times and operation in varying light levels. Further testing and development remain to be done. This is the type of application that will make imaging and artificial vision an economic reality for other commercial areas as well.

Vision for the Blind. A second application of this low-resolution imaging technology was an optical navigation and recognition package for the totally blind. In the past, two approaches

have been taken with this kind of program. The first approach uses an optical wand that drives a tactile output device. The second involves an xy matrix sensor that would be decoded into a pattern to be impressed onto the cortex of the brain. Both techniques require that the user interpret the image acquired by the equipment. Additionally, the second technique requires a surgical procedure to implant the microcomputer, which will generate a neurologically compatible pattern. Removal of the subject's eye(s) will be necessary so that the semiconductor eye may be attached to the eye muscles. Because of the procedure and training, this system will be limited to extreme cases (see figure 5).

The purpose of this project was to use current industrial imaging techniques to create an artificial vision system for the handicapped. The imager employed in this design is a low-cost 1 by 16 industrial sensor manufactured by Cyberanimation Inc. of Akron, Ohio, and that was originally developed for simple pattern-recognition equipment. It is placed in a belt-buckle-sized housing that is worn about a person's waist. The sensor is aimed about four feet in front of the person, so use of a cane or seeing eye dog is still possible (figure 6).

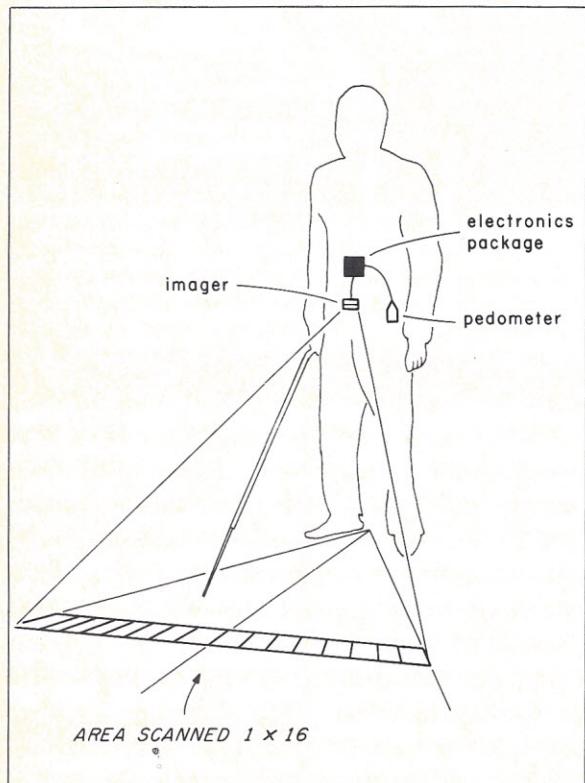


Figure 6: This concept of artificial vision for the blind uses a belt buckle-sized 1 by 16 industrial imaging array. The array is worn about the waist and is aimed at the ground four feet in front of the user.

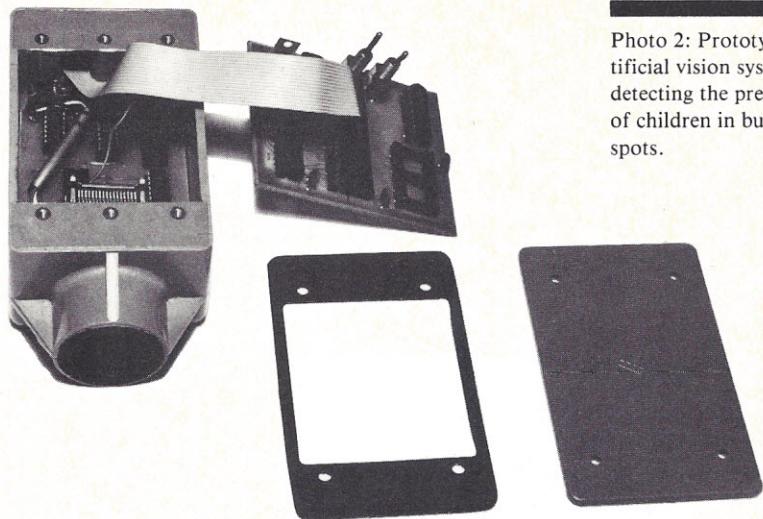


Photo 2: Prototype artificial vision system for detecting the presence of children in bus blind spots.

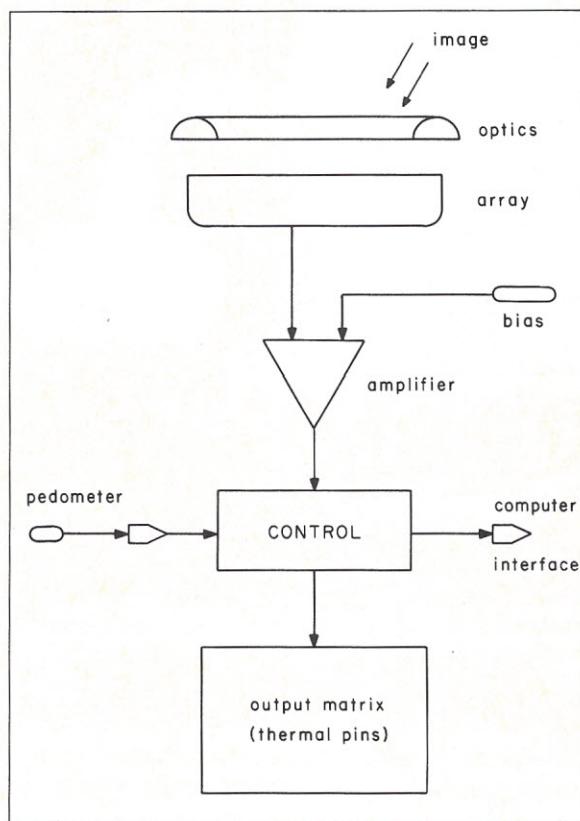


Figure 7: A block diagram of the optical navigation unit. The system consists of optics that focus the image, the array, electronic scanning and amplification, a gross bias adjust, a control circuit with pedometer input, and interface to the computer or a matrix of thermal pins.

Two output schemes were developed for the imager. The first and simplest was a 1 by 16 set of thermal pins placed against the body. The pins would change temperature to indicate variations in scene illumination. As the wearer walks, the image changes, giving a thermal image of obstacles. The second scheme involves using a pocket computer to do simple analysis of the environment (see figure 7). The imaging circuit is almost the same as the first version, but a pedometer switch has been added so the image can be analyzed as a function of the walker's gait.

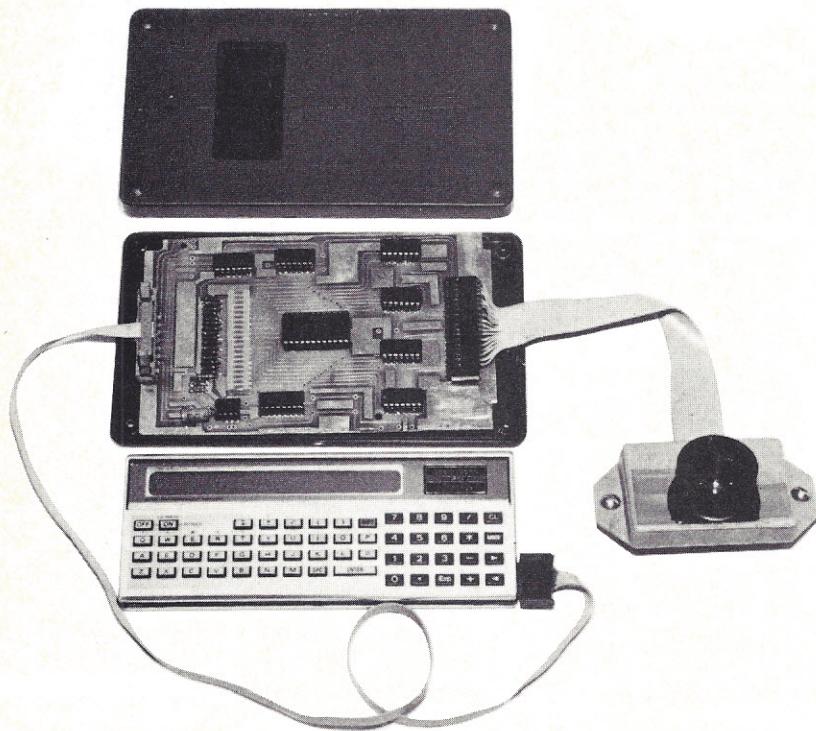


Photo 3: A prototype vision system that translates various light intensities into thermal changes in a belt worn about the waist.

The software for this system is fairly simple, permitting the system to run at near real-time speeds. In the walking mode, the basic function of the software is to identify possible obstructions and their locations. This is accomplished by looking for continuous vertical bands or wide horizontal bands in the image. Their location is then beeped out by the computer. Since the imaging is performed several feet in front of the walker, he is able to use a cane to explore the obstruction before his feet encounter it.

A second mode in which this system can be used is optical character recognition (see figure 8). This feature is important to the blind since many objects, including printed material and small, delicate objects, can only be discerned by optical means. In this mode the system functions

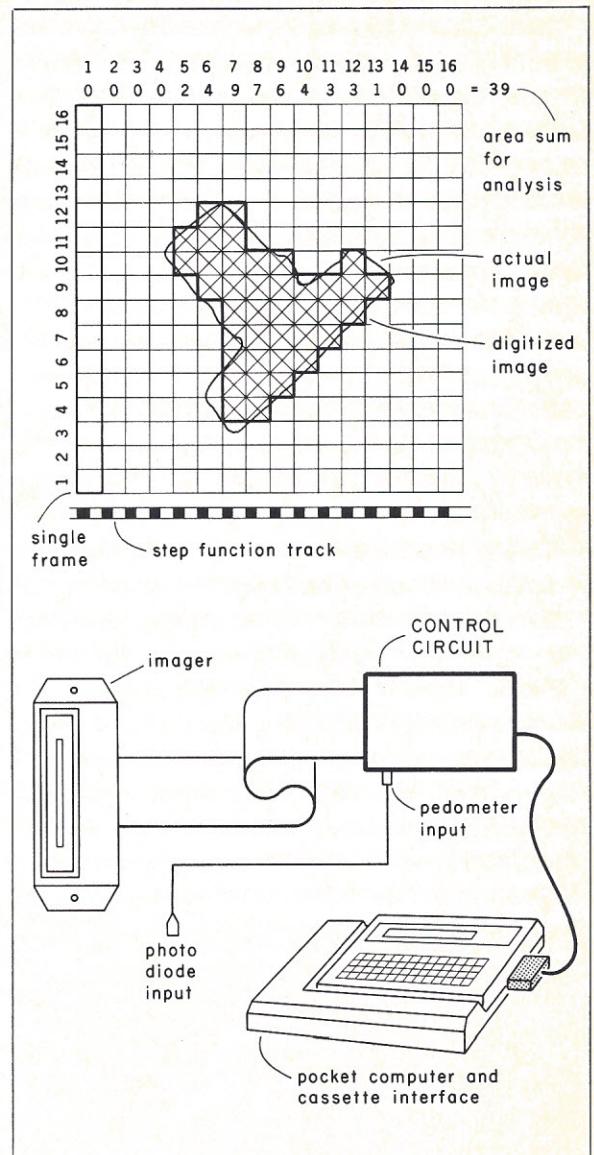


Figure 8: In addition to a walking mode, the optical navigation unit has a pattern recognition mode that allows printed material and small objects to be scanned. The system can recognize objects using various techniques. Information is conveyed by a series of beeps emitted by the computer.

as a traditional industrial robot that performs high-contrast binary imaging. Analysis includes area, connectivity, perimeter, and template, and, like an industrial robot, the system understands nothing about the image but is able to repeatedly identify objects by their optical pattern. Some handy applications are reading money denominations and small blocks of text. Photo 3 shows the prototype system and the complete imaging kit.

The above examples mark only the beginning of artificial vision products. Many groups across the country are working on newer and more sophisticated products to make the places where we live and work safer and more productive. □

ROBOTS VI

A LANDMARK IN AN EXCITING ERA

BY GLEN W. SWANSON, PUBLISHER, *ROBOTICS AGE*

Thursday Morning, March 4. The shuttle bus crept slowly along the snow-clogged highway from the airport hotel to Cobo Hall in downtown Detroit. As my fellow passengers and I gazed out at cars abandoned on embankments, we wondered how many people would brave the storm to attend the last day of Robots VI. Within hours we had our answer. At Cobo Hall spectators surged through the aisles, looking, listening, touching, sensing what this new age of robotics was all about. Although the sponsors had expected more than 8000 attendees for the entire Robots VI Conference and Exposition, they were surprised, and overwhelmed, when total attendance exceeded 27,000 (the fire marshal had to close the doors for several hours on Wednesday because of the crowd).

Sponsored by Robotics International of the Society of Manufacturing Engineers (RI/SME) and the Robot Institute of America (RIA), the Robots VI program included four days of sessions with more than 80 speakers, and three days of equipment demonstrations put on by approximately 100 exhibitors. The sessions covered robot technology, education and training, applications, research and development, and implementation.

Exhibitors demonstrated robots, sensors, material handling equipment, painting and coating systems, welding systems, assembly systems, machine loading, inspection, and testing applications.

The exhibits covered a wide spectrum of robotics engineering and applications, integrating mechanical and electronic engineering knowledge with practical system design. Leaders of industry displayed their wares and expertise as they combined mechanical mechanisms with microcomputers, software, and sensor technology.

The spirit of American entrepreneurship filled the showrooms. Small- and medium-size firms exhibited the products of their research and development. The non-industrial sector was also well represented by financial analysts, writers and publishers, educational leaders, and consultants. The governor of Michigan appeared, highlighting that state's desire to present itself as the center of the American robotics industry.

What About the Robots? They were impressive in their number. Nearly all the identifiable "robots" at the show were of the manipulator arm variety. Not only were there robots, but also vision systems, motors, con-

trollers, software packages, grippers, modular kits, and even a leasing company. There were robots to spot weld, arc weld, spray paint, assemble, load/unload, handle parts, sharpen pencils, and hand out brochures. Some were more than 14 feet high, yet some were smaller than a breadbox.

Although space does not permit us to describe the many different systems on display, a sampling of the products that caught our attention is presented below and in the accompanying photo essay by Jack Shimek.

Seiko introduced its first servo-controlled robot to complement its popular line of pneumatic robots. General Numeric showed a new servo robot in a very well thought-out display of most of its product line at work performing real-world tasks in a machine tool and assembly environment. United States Robots showed its Maker assembling parts in conjunction with a rotary indexing system. Cincinnati Milacron presented its new HT³ which is a smaller complement to its huge T³. SI Handling Systems displayed its expertise with a precision conveying system. Automatix's robot welded together two metal plates by following an irregular seam. Object Recognition Systems provided a popular booth with its vision system demonstration. Graco Robotics showed its OM-5000 spray-painting robot, dubbed "The Easy Robot."

Acco had one of the larger units on display, a high frame that housed a sorting assembly for stock handling. Schrader Bellows, a manufacturer of valves, regulators, and gauges displayed its own newly developed pneumatic robot. Reis Machines had a reachable robot on display. Westinghouse's new Industry Automation Division announced a wide variety of robots ranging in function from small component assemblers through arc welding systems and programmable welding systems.

Robots VI was a highly successful event for a burgeoning American robotics industry. In addition to providing time for sharing knowledge, opinions, and questions with engineers, production managers, marketing executives, industrialists, and robot experts, the conference also signalled the American public's increasing awareness of this age of robotics. We wish to thank the Robot Institute of America and the Robotics International of the Society of Manufacturing Engineers for their successful show. We look forward to Robots VII, which will be held at a much larger facility in Chicago in April 1983. □

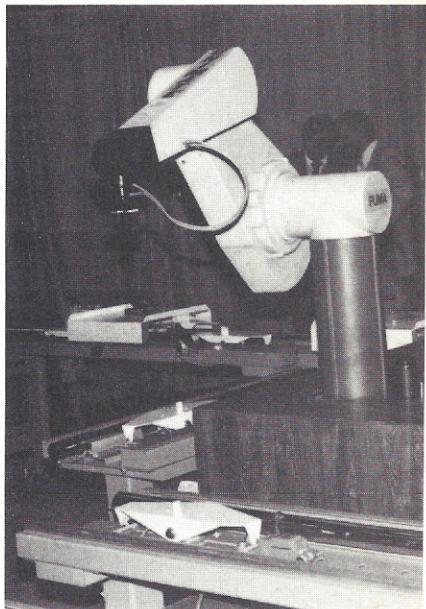
PHOTO ESSAY AND NOTES FROM ROBOTS VI

by Jack Shimek

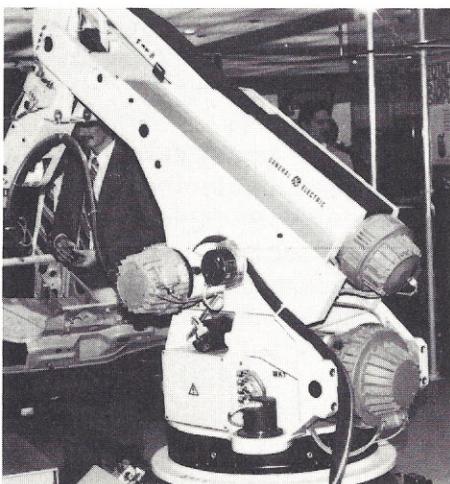
One of the antecedents for modern robotic technology is the kind of hydraulic crane often installed on commercial delivery trucks. These are adapted in everyday use as remote access platforms, construction materials loading systems, and log handling equipment in the forest product industries. This Marol Company Ltd. hydraulic manipulation system seen at Robots VI is a straightforward adaptation of conventional design as a general purpose heavy duty telemanipulator. It is also said to accept commands from electronic systems, allowing it to operate in a true robot mode. Demonstrations at Robots VI were often made with an operator controlling the manipulator from the panel on the platform attached to its column.



Unimation's PUMA arm is one of the classics of recent servo-controlled electric arm design. It traces its roots to Victor Scheinman's design concepts seen over the last two decades in laboratories at MIT, Stanford, and SRI. It is widely used in automotive assembly tasks as well as its predecessors from this pioneering robotics firm. There are several different models in the PUMA line from Unimation, complementing their larger hydraulic robots.



General Electric had one of the largest booths at the 1982 Robots VI show. This heavy duty electrical arm was one of the many GE products on exhibit. It is shown here in an automotive manufacturing context. Much of GE's instant presence in the robotics field is said to rely on European and Japanese designs.



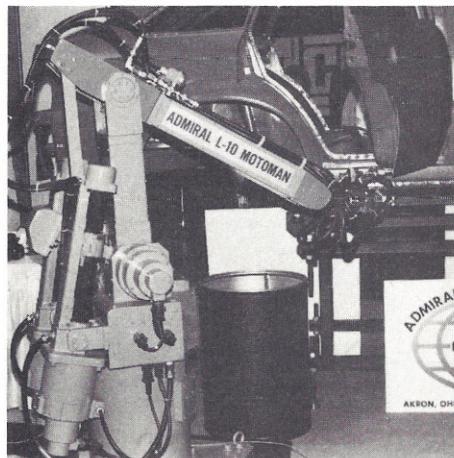
The number of observers at the show emphasize the growing interest in robotics. This picture, provided by the Robots VI sponsor, Robotics International of the Society of Manufacturing Engineers, includes several prominent SME members and Michigan's governor William G. Milliken. George Munson

of Unimation, chairman of the conference, is shown pointing to the Unimation PUMA robot at the right. Looking on to his left is John DiPonio, first president of RI/SME. Governor Milliken is leaning on the exhibit's boundary wall to the right of Mr. Munson.

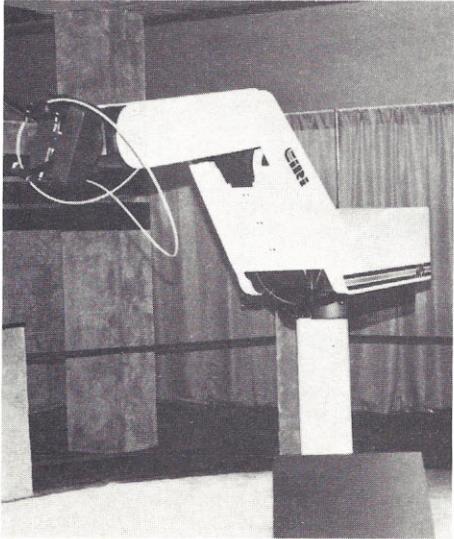
This light weight arm produced by ASEA Inc. is one of the most widely used — and — copied designs on the market. It has been used for several years in applications that require precision manipulation rather than heavy duty lifting ability. An optional vision system is said to be available for the arm.



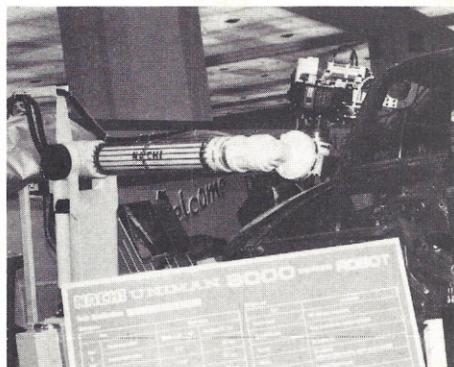
The Yaskawa Motoman robot arm is shown in an automotive sealant dispensing application at the booth of Admiral Equipment Company, a subsidiary of The Upjohn Company located in Akron, Ohio. This was one of a number of OEM (original equipment manufacturer) users of the Yaskawa technology on the floor of the Robots VI show. The Yaskawa robots feature well engineered servo-controlled electrical drives.



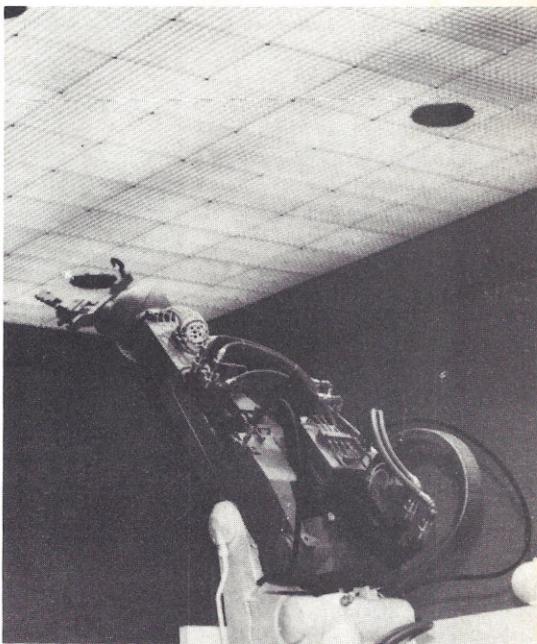
The International Robomation/Intelligence manipulator is one of the most cost effective servo controlled pneumatic manipulators available. The active control of five axes is provided by an advanced 68000 microprocessor coupled to individual microprocessors dedicated to each degree of freedom. The local 68000 central processor is said to be able to act as its own development system, supporting both FORTRAN and Pascal. This kind of computer capability is necessary in order for customers to develop advanced vision and sensor strategies.



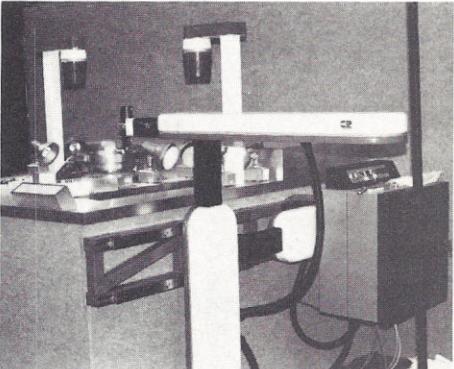
The NACHI Uniman 8000 series robot was on line at the show, simulating an automotive spot welding operation. The same pattern of dummy welds was performed over and over again with no discernible variation. Produced by the Nachi-Fujikoshi Corporation/Machine Tool Division of Tokyo, this product marked the company's introduction to the North American market.



The Robotics Division of the Bendix Corporation, Southfield, Michigan, demonstrated two arms at Robots VI. This long reach electric arm can position 150-pound objects with a repeatability of $(+/-) 0.005$ inch. A second manipulator was on display, featuring a 45-pound lift capacity and 0.002 inch repeatability. This illustrates in practice the design tradeoff between payload and precision of placement. The Bendix manipulators were designed for machine tool loading and parts transfer operations.



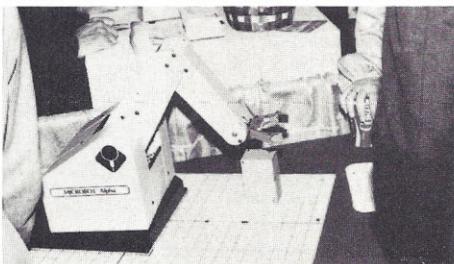
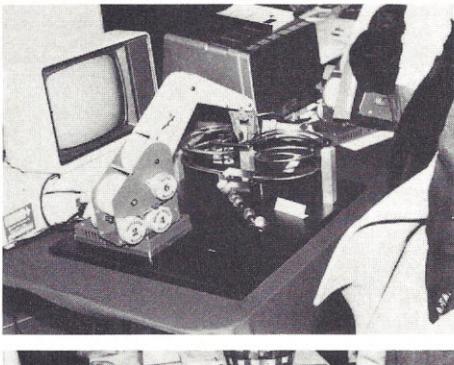
Copperweld Robotics Inc. demonstrated a CR-100 pneumatic positioning and manipulation system. In the past, typical pneumatic robot designs involved mechanical stops that fix the limits of motion in particular degrees of freedom. Later models, such as this, feature servo control and complete programmability via manual lead through or direct command from a host computer system. The Copperweld Robotics line also includes vision options.



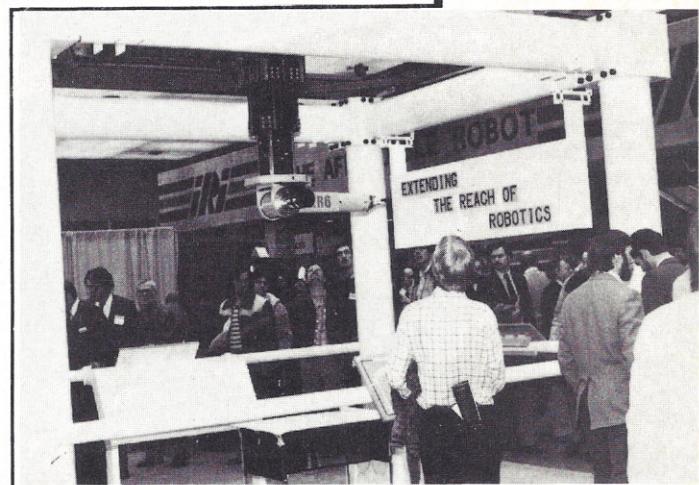
One of the finest representatives of a trend toward modularity is provided by this line of robotic components from Manca Inc., the U.S. distributor for Fibro GmbH of West Germany. With modules such as these (left) it is possible to assemble many different configurations (shown at right). Modularity coupled with high precision requires extra care in design and manufacturing, and that is quite obviously present in this line.



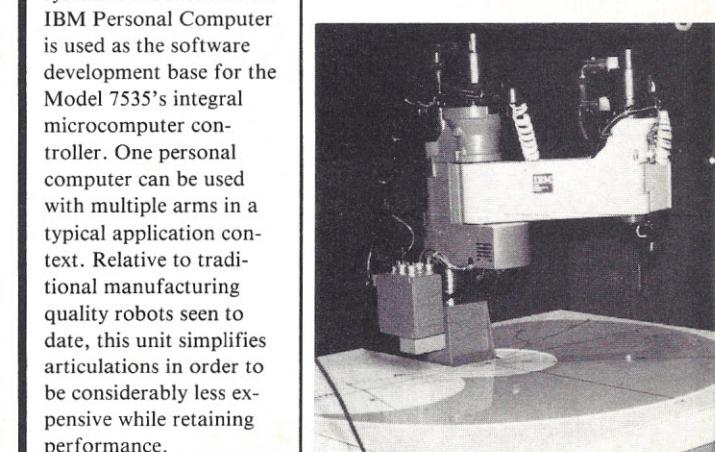
Several variations of Microbot technology were in evidence at the Robots VI show. At top we see the original Mini-Mover, still one of the least expensive robot systems at about \$1700. This relatively slow low-cost arm attaches to 8-bit parallel interfaces available for any small personal computer. A newer version (not shown here) is called the Teach Mover, due to its integrated microprocessor controller. The newest design from Microbot shown at bottom, is the Microbot Alpha arm, a faster product intended for light industrial markets. Its low cost is due to continued use of stepper motor open loop control.



The Prab factory automation manipulator is said to be able to lift 600 pounds through a wide envelope. The repeatability is said to be .050 inch, not bad for such a load.



The entry of IBM into robotics was one of the more significant events of this year's Robots VI show. Its first product in the marketplace is a Japanese-designed and manufactured light assembly robot called the Model 7535 Manufacturing System. An interesting aspect of this system is the fact that the IBM Personal Computer is used as the software development base for the Model 7535's integral microcomputer controller. One personal computer can be used with multiple arms in a typical application context. Relative to traditional manufacturing quality robots seen to date, this unit simplifies articulations in order to be considerably less expensive while retaining performance.



One of the latest trends in manufacturing robot design is toward constrained travelling schemes, an intermediate concept between that of a free roving autonomous machine and a fixed base device. This new XR-6 series of robots from GCA Corporation's PaR Systems operation is a typical example of exploration into this design area. The overhead trolley arrangement used

New Products

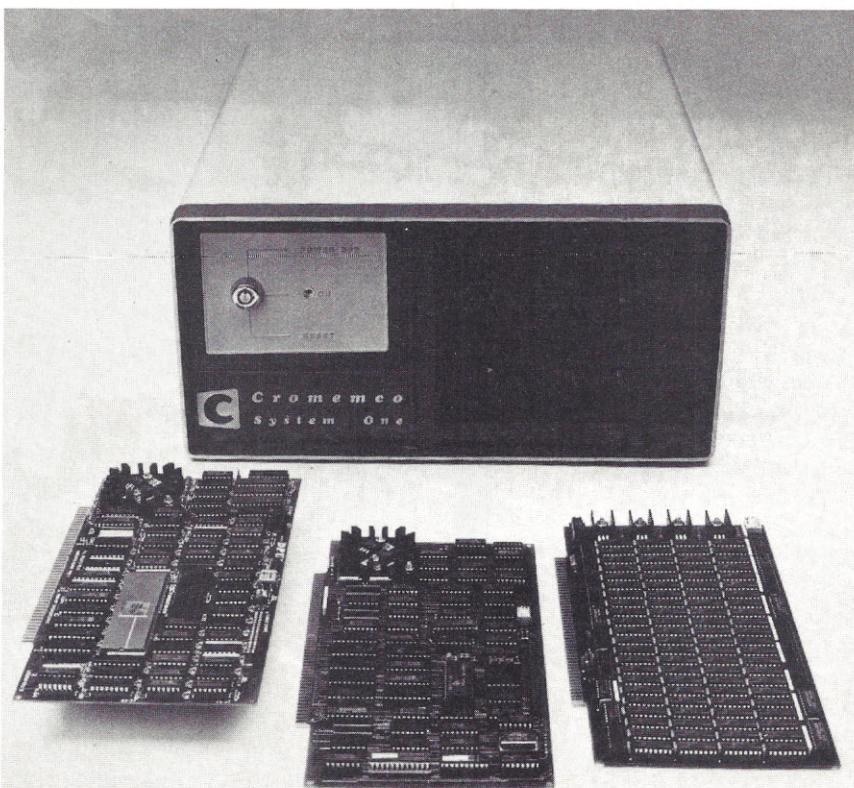
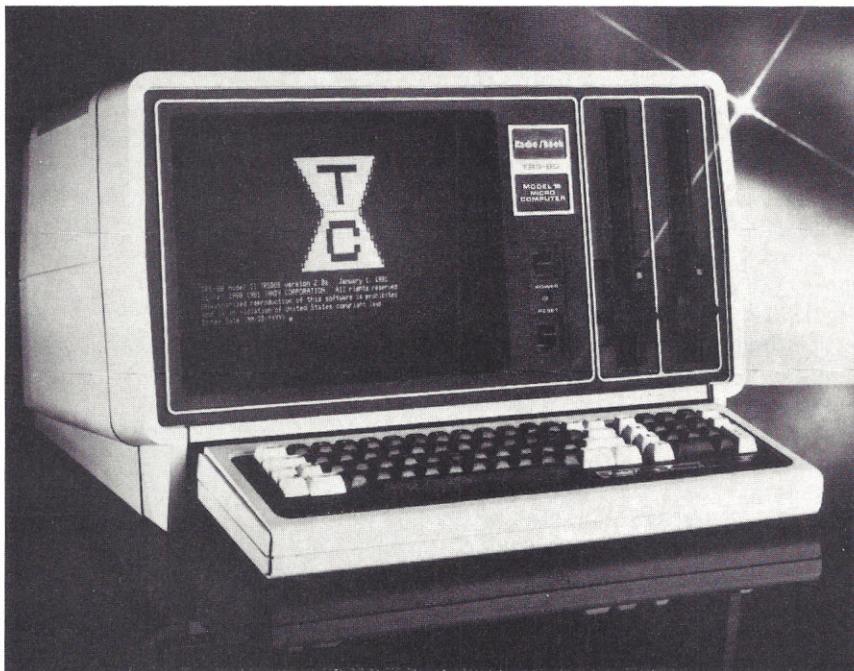
The 68000 Explosion

The number of 68000-based computers and systems has increased dramatically. Most recently, these three have come to our attention.

Tandy has introduced a 68000-based system called TRS-80 Model 16 with 512K bytes of internal memory storage and 2.5 Mbytes of disk memory. The Model 16 uses two microprocessors: a 68000 and a Z80A. The Z80A provides software compatibility with existing TRS-80 Model II software and also relieves the 68000 from time-consuming chores such as input and output. The system has been designed for use in a multi-user environment. By adding one or two additional terminals, three users can access programs and information at the same time.

The WICAT System 150 from Concurrent Corporation contains an 8 MHz 68000 with memory expandable up to 1 Mbyte and provides advanced editing capabilities with optional high-resolution graphics. Mass storage options include 5 1/4-inch floppy diskettes and a 10 Mbyte 5 1/2-Winchester drive. The System 150 has been designed to meet UL and CSA safety ratings. Several operating systems are supported including UNIX version 7 and a CP/M emulator that permits existing CP/M programs to run independent of other users. With appropriate options, the System 150 can be used in a multi-user environment, supporting up to five external terminals.

Finally, Cromemco has announced a dual processor unit (which they refer to as a DPU) that contains a 68000 and a Z80A on a single S-100 board. The Z80A is included to provide compatibility with the large library of existing 8-bit software, and it also provides an inexpensive upgrade path for current Cromemco owners. The system supports CROMIX, which is described as "a user friendly version of UNIX." Cromemco has also announced a family of error correcting memory boards. The two memory boards (containing 256K and 512K bytes of memory) use an additional 22 bits to encode each



16-bit word to provide error checking and correction using a modified Hamming code. This method allows

transparent detection and correction of single bit errors and detection of double bit errors.

New Products

IBM Announces Low-Cost Robotic System

IBM has announced a low-cost, programmable robotic system — the IBM 7535 — and expanded test marketing of an advanced robotics system, the IBM RS 1.

The IBM RS 1, designed for precision automatic assembly, combines sophisticated tactile and optical-sensing capabilities with six degrees of freedom — the ability to move its arm in six directions. A powerful and easy-to-use programming language, AML (A Manufacturing Language), has been developed by IBM to direct the RS 1's operations. "We believe AML is the most advanced robotic control language in the world," said Dr. David D. Grossman, manager of automation research at the IBM research center.

The RS 1 is used for precision assembly, electronics parts insertion and other intricate operations, and can respond moment-by-moment to changes in its work environment.

Currently the system is installed in a test marketing program underway at a limited number of customer locations and at IBM manufacturing facilities.

The IBM 7535 Manufacturing System is capable of four degrees of freedom, and quickly and precisely performs a broad range of industrial tasks.

The low-cost system automatically assembles, packs, loads, and unloads parts with repeatable precision, offering automotive, appliance, cosmetics, electronics, and other manufacturers the opportunity to rapidly automate many production jobs at low cost. Multiple 7535s can be programmed with a single IBM Personal Computer using an entry-level version of AML.

The IBM 7535 can be purchased for \$28,500. Quantity discounts of up to 15 percent are available. The IBM Personal Computer configuration used to program the IBM 7535, including programs, can be purchased for \$5575.

Deliveries of the IBM 7535, built for

IBM by Sankyo Seiki Manufacturing Company Ltd., Tokyo, are scheduled to begin in the fourth quarter of this year. For further information on both systems, contact IBM, System Products Division, 1000 N.W. 51st St., Boca Raton, FL 33432. CIRCLE 21



New Products

Symbolics Software Overview Available

The Symbolics Software document, from Symbolics Inc., discusses the user interface to the Symbolics system, which includes the window system (manages the bit mapped display), the file system, the text editor, the mail reader, and other interactive systems and tools.

Both system programs and user programs on the Symbolics machines are written in Zetalisp, a dialect of Lisp derived from MIT's MacLisp. The Symbolics Software document describes the Zetalisp programming environment, discussing features of the language itself as well as the tools provided by the system to make programming easier.

All software described in the document is fully operative and has been tested by an enthusiastic and demanding user community, whose suggested improvements have been continually integrated into the Symbolics software system. All Symbolics software is sold with complete sources and maintenance for one year.

To receive a copy of Symbolics Software, contact Symbolics Inc., 21150 Califa St., Woodland Hills, CA 91367, or call (213) 347-9224. CIRCLE 22

IRI Introduces Inexpensive Robot

International Robomation/Intelligence has produced a seven-microcomputer air-servo-motor-controlled 50-pound payload robot for \$9800. The robot is completely self-contained in a lightweight unit that can be mounted on a base of any height. Each of five axes is controlled by an air-servo motor.

An internal 68000 with 128K bytes of memory handles both on-line and off-line programming, local and global networking, and higher-level languages. For information, contact Erwin Allen, IRI, 6353 El Camino Real, Carlsbad, CA 92008, (714) 438-4424. CIRCLE 23

Prab Introduces Advanced Robot Microprocessor Control

The Model 500 robot controller from Prab Robots Inc. simplifies robot operation by reducing the entire control to one printed circuit board. This advancement allows manufacturers to use sophisticated robots without a complex controller. It will be applied to tasks with Prab's Model E, FA, FB and FC robots.

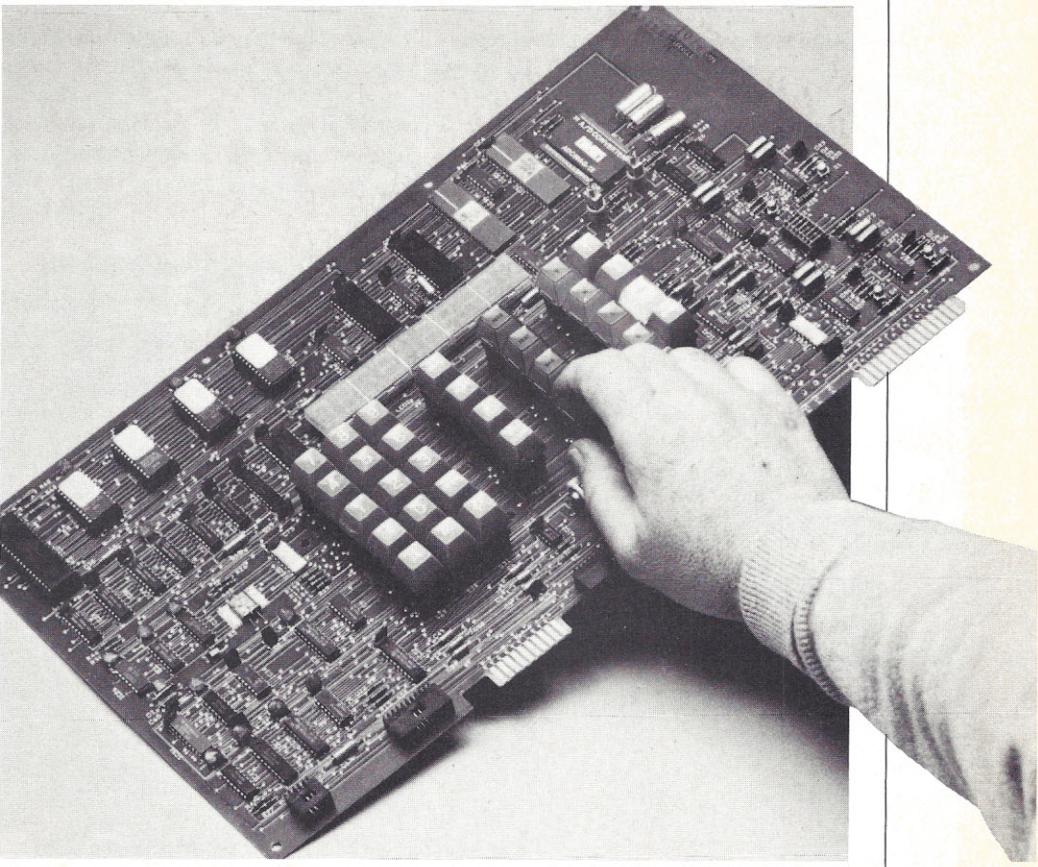
All basic operations of the new controller, for starting and stopping the robot's operation, can be conducted from the front panel buttons. The programming keyboard and digital displays are mounted to the single circuit board. These features are locked behind the front panel, but remain easily accessible for task programming with the cabinet door opened. Programming is accomplished through the main panel with a hand-held teach unit or direct keyboard entry. This arrangement reduces the

chance of inadvertent alterations or program erasures.

The Model 500's single circuit board utilizes an advanced microprocessor. All of the robot's operating characteristics, including acceleration, deceleration, velocity, and mechanical functions, are software-controlled.

The system has the flexibility to support resolver feedback, as well as other types of sensors. The advanced diagnostics system in the software continually checks the control hardware for correct operation. If a problem should occur, the appropriate action is taken and a read-out displays a diagnostics error message. With only one adjustment per servo axis, maintenance for the 500 is extremely simple.

For more information, contact Prab Robotics Inc., 5944 East Kilgore Rd., Kalamazoo, MI 49003. CIRCLE 24



New Products

Concurrent CP/M-86

Concurrent CP/M-86 is the first operating system for 8086- or 8088-based microcomputers that is designed to allow a single user to perform several jobs simultaneously.

With Concurrent CP/M-86, a user can, for example, print a file, enter information into a database, and receive electronic mail from a communications port, all at the same time. If the user

forgets a file name, he or she can call up a directory without leaving the current program. Programmers can save time by compiling one segment of code while editing another. The push of a key allows users to go from one screen to another to monitor several operations running simultaneously.

Concurrent CP/M-86 offers file-structure compatibility with all Digital

Research operating systems, including CP/NET. Programs running under Concurrent CP/M-86 can directly address up to 1 megabyte of memory. The system can support 16 logical drives, each containing up to 512 megabytes, for a maximum of 8 gigabytes of on-line storage.

Other features include a real-time kernel; record and file locking; date and time stamps; password protection on files; error-handling and reporting; network compatibility and multiprogramming capability.

The first implementation of Concurrent CP/M-86 will be on the IBM Displaywriter, with versions for other microcomputers to follow. (Standard CP/M-86 is already available for the Displaywriter.)

Digital Research will begin taking orders for Concurrent CP/M-86 in mid-April. For more product and price information contact Jim Handy, Digital Research, POB 579, Pacific Grove, CA 93950.

CIRCLE 26

16-Bit Single-Board Microcomputer

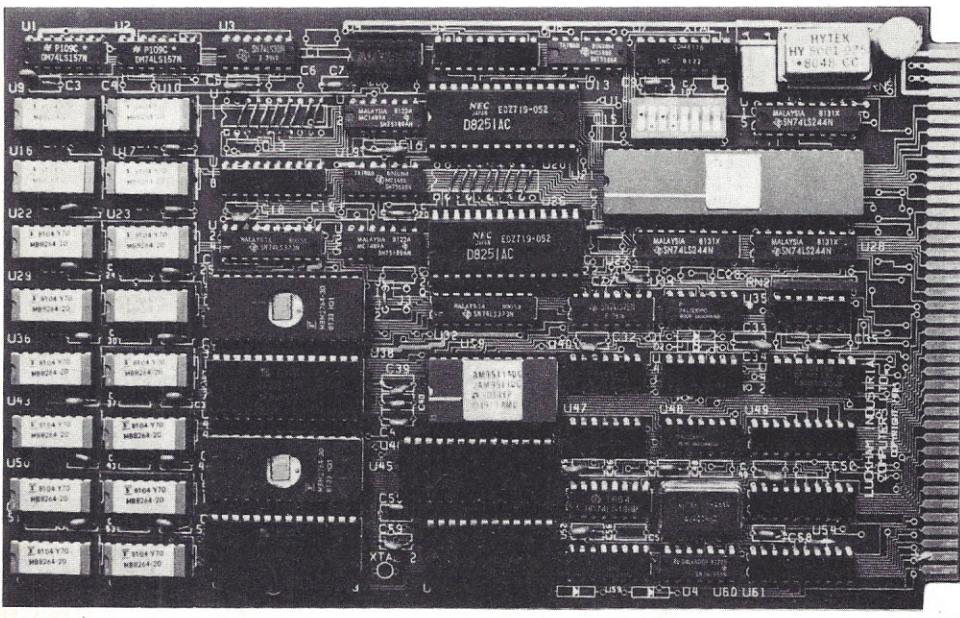
Innovative Electronics Technology of British Columbia, Canada, now offers its 16-bit, Z8001 single-board microcomputer, PROTEUS. The processor board is a compact 146 by 221 mm (5 3/4 by 8 3/4 inches) in size, and contains a 4 MHz Z8001, two serial ports, and a real-time clock. The board also contains 128K of dynamic user memory, 8K of static system memory, and 16K of read-only memory containing the two user BiTOS operating system. All I/O is interrupt-driven, and a 9511/12 floating point processor is optional.

IET offers PROTEUS both as a single board and as part of a minifloppy-based

development system. The latter comes packaged in a rugged steel case holding the processor board, a floppy controller board, and a double-density, 800-track TEAC drive (320K). A prototyping board for wirewrap design is extra. Software supplied with the system includes Microsoft BASIC-8000. An editor-assembler package is available.

The single-board product is available for \$2485, and the development system, model PF-128FXL, is priced at \$4860. OEM prices are also available. Contact Gerard Obery, IET, 6993A Antrim Ave., Burnaby, British Columbia, Canada V5J 4M5.

CIRCLE 25



Bin-Picking System

Object Recognition Systems Inc. has developed a new robot vision capability known as "bin-picking," as part of an advanced vision module for industrial robots still under development. A robot arm connected to the vision system can retrieve various parts that have been jumbled together in a bin. The robot's vision system first locates and identifies the correct part, whatever its orientation, and the arm is maneuvered into the correct position for grasping the part. The algorithm used for the bin-picking capability will be combined with other algorithms in an integrated robot vision system with comprehensive capabilities now under development. For further information, contact Fritz Lyon, Object Recognition Systems Inc., 521 Fifth Ave., 17th floor, New York, NY 10175, or call (212) 682-3535.

CIRCLE 27

New Products

Low-Cost Z80 Microcomputer Kit

Microcomputers designed around the Z80 have provided an excellent choice for the business-oriented user, but in the past there was no economical system that could meet the needs of students, teachers, and experimenters who wished to evaluate the Z80's performance. With the advent of the PRO/80, this void has been filled.

The PRO/80 includes an S-100 bus that allows users to expand their systems at will by choosing from various modules already available on the market. Extra wire wrapping space has been left for experimentation and the building of process control circuits on the prime circuit board. The PRO/80 also has two parallel I/O ports that permit access to external peripheral equipment. These two ports possess 8 bits each, and each bit can be controlled by software, assuring the user control of 16 individual lines for particular applications. An interface for an audio cassette provides the user with an economical means of recording programs and data directly on tape.

The PRO/80 memory is 1K of programmable memory expandable on the board to 2K bytes. A third kilobyte of EPROM contains the monitor, which performs several powerful functions such as memory examine and change, register examine and change, next memory location, next alternate register, and a single step operation mode that provides the user with the capability to execute and debug programs one instruction at a time. Other functions such as reset, program execute, and cassette read/write are also featured.

A hex keyboard with an additional eight keys is used to load data and programs and to initiate the different functions of the monitor. Six seven-segment digits are used to display the memory addresses, the Z80 registers, the alternate registers, and their contents.

The PRO/80 requires only an 8 V, 1 amp transformer to supply the required voltage. Complete instructions are supplied so that the kit can be built in a

minimum amount of time, even by the novice constructor. A manual is supplied to give the user additional information. The kit is priced at \$169.95. For more information, contact ETCO Electronics, Plattsburgh, NY 12901.

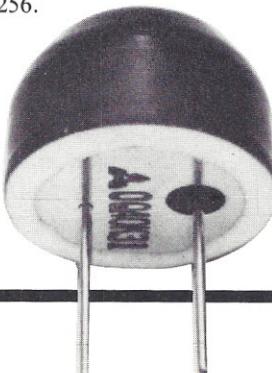
CIRCLE 28

Enclosed Ultrasonic Ceramic Microphone

An enclosed ultrasonic ceramic microphone is available from the Electronic Components Division of Panasonic Industrial Company. Unlike previously available microphones, this new device is completely enclosed, thus offering increased resistance to water and dust, as well as more rugged construction.

Applications for the new device include burglar alarms, distance measuring transducers, back-up alarms for motor vehicles, automatic door openers, and remote controlled appliances or devices. The microphone can be used either as a receiver or a transmitter (converting mechanical energy into an electrical signal in the first case, or electrical energy into mechanical in the second). When used as a receiver, its center frequency is 40 kHz and sensitivity is -75 dB/ubar; when used as a transmitter, its center frequency is also 40 kHz and sound pressure level (SPL) is 105 dB minimum. For either receiver or transmitter, maximum input voltage is 20 V (rms) and the bandwidth is 2 kHz minimum.

For more information, contact Harvey Lewin, One Panasonic Way, Secaucus, NJ 07094, or call (201) 348-5256.



CIRCLE 29

MICRO/T-11

Digital Equipment Corporation has announced the first of a series of chip-level PDP-11 microprocessors. Called MICRO/T-11, the chip is a 16-bit 40-pin microprocessor with a base-level PDP-11 instruction set.

The MICRO/T-11 can be operated with a variety of industry standard devices with a user-selectable 16- or 8-bit data bus, and it is used as the central processing unit for the recently announced Falcon SBC-11/21. The microprocessor enables high volume Original Equipment Manufacturers (OEMs) to employ chip-level integration of PDP-11 instructions for a wide range of applications. It is particularly suitable for controller-type applications.

Application programs can be developed for MICRO/T-11 on PDP-11 minicomputer or microcomputer systems using the MACRO 11 assembly language. Programmers familiar with PDP-11 programming at the assembly level can generate application programs for MICRO/T-11 without specialized training.

MICRO/T-11 will be available in limited sample quantities beginning in April, with volume shipments scheduled to begin in the summer. The MICRO/T-11 unit price is \$75 in volumes greater than 1000. It will be marketed exclusively by Digital. For further information, contact DEC, Maynard, MA 01754.

CIRCLE 30

Robot Simulation

GRASP (General Robot Arm Simulation Program) allows a graphic simulation of a real or imaginary robot and associated working area. The program, which currently runs on a Prime-Imlac System, can be used to evaluate and compare robots in their working environments. For more information, write GRASP Inc., 102 14th St., Troy, NY 12180.

CIRCLE 31

New Products

New Programmable Robot

Schrader Bellows Division of Scovill has introduced a microprocessor-controlled programmable robot for under \$12,000.

MotionMate, a 5-axis, pneumatically powered industrial robot, has a maximum payload of 5 pounds, can operate at speeds up to 24 inches per second, and has a repeatability of $\pm .005$ inches. It is ideal for light assembly applications, loading and unloading machines, and machine to machine parts transfer. Axes of movement include base rotation to 180 degrees, lift to 3 inches, extension to 12 inches, wrist of 90 degrees or 180 degrees, and grasp.

A microprocessor controller operates the robot from memory and interfaces with other equipment associated with

the overall automated function. Programming is done on a hand-held teach module that uses simple graphics symbols for robot commands and requires no special operator skills. Such programming simplicity gives MotionMate the flexibility necessary for quick, easy changes to new production requirements.

MotionMate can be supplied with all five axes of motion or as modules for applications that require fewer axes. The robots are built with proven, standard Schrader Bellows fluid power components, at economical prices, with quick delivery and worldwide service.

For more information, write for catalog MM-1, from Schrader Bellows Division, 200 West Exchange St., Akron, OH 44309.

CIRCLE 32



MTU Announces Fast 6502-Based Computer

After years of designing add on and expansion peripherals for 6502-based computers, Micro Technology Unlimited has developed their own 6502-based computer. The MTU-130 contains a 1 MHz 6502 with an extended address bus capable of addressing 256K bytes of memory. High-resolution graphics are supported with a 480 by 256 pixel screen or 240 by 256 pixels with four gray levels. Other niceties include capability for digitized speech and music synthesis, a fiber optic light pen, and a UNIX-like operating system called CODOS.

The standard system containing 80K bytes of memory, console, monitor, one disk drive (1 megabyte of memory), the operating system, and BASIC sells for \$2999. For more information, contact Micro Technology Unlimited, POB 12106, 2806 Hillsborough St., Raleigh, NC 27605.

CIRCLE 33

Bullet Single-Board Computer

The Wave Mate Bullet, a 4 MHz Z80A single-board computer, is designed to efficiently run CP/M-based software. The computer contains 128K bytes of user memory, single/double density floppy disk controller for 5½- and 8-inch drives, two serial I/O ports, a Centronics printer port, and an interface for an IMI or Corvus Winchester drive, along with a one year limited warranty. The operating system can be either CP/M Version 2.2 for a single user system or MP/M Version 2.0 for a two-user system. The computer is available as a single board or integrated with disk drives and cabinet for a complete computer system. For more information, contact Wave Mate Inc., 14009 South Crenshaw Blvd., Hawthorne, CA 90250.

CIRCLE 34

Now your robot can see like a hawk!



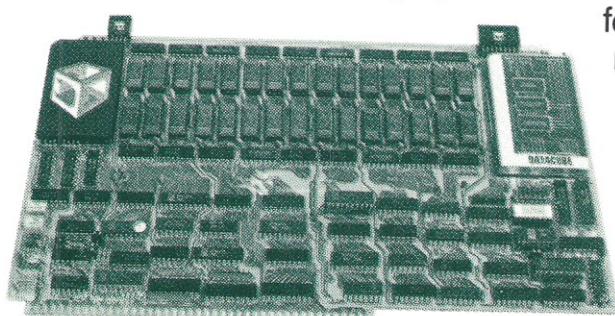
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- Program segmentability
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- Built-in powerful string-handling features

TELESOFT¹ ADA⁴

- Designed to fulfill all DoD specifications
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CIRCLE 5

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